COUNTWAY LIBRARY
HC 4ZSW %

6 E 456

BOSTON MEDICAL LIBRARY

PURCHASED FROM FUNDS GIVEN BY

DR. JOHN MARTYN HARLOW

BONES AND JOINTS

MEDICAL AND SURGICAL THERAPY

EDITED BY

SURGEON-GENERAL SIR ALFRED KEOGH
K.C.B., C.B., LL.D., M.D., &c.

FOREWORD BY

WILLIAM C. GORGAS
SURGEON-GENERAL U. S. A.

VOLUME V

BONES AND JOINTS

D. APPLETON AND COMPANY
NEW YORK AND LONDON
1918

15385

Copyright, 1918, by
D. Appleton and Company

BOSTON MEDICAL
JUN 20 1918
LIBRARY

Printed in the United States of America

BONES AND JOINTS

LOCALISATION AND EXTRACTION OF PROJECTILES

ARTIFICIAL LIMBS

AFTER EFFECTS OF WOUNDS OF THE BONES AND JOINTS

WAR OTITIS AND WAR DEAFNESS

BY

L. OMBREDANNE
R. LEDOUX-LEBARD
A. BROCA
DUCROQUET
H. BOURGEOIS
M. SOURDILLE

D. APPLETON AND COMPANY
NEW YORK AND LONDON
1918

Copyright, 1918, by
D. Appleton and Company

Printed in the United States of America

CONTENTS

SECTION I

LOCALISATION AND EXTRACTION OF PROJECTILES

BY

L. OMBREDANNE AND R. LEDOUX-LEBARD

		PAGE
CHAPTER I.	PRODUCTION OF X-RAYS	1
	Tubes	1
	High Voltage Sources	8
	Adjustment of the Tubes	12
CHAPTER II.	X-RAYS AND THEIR CHIEF PROPERTIES	21
	Radioscopy	29
	Radiography	34
CHAPTER III.	LAWS OF PROJECTION	43
	Primary Ideas on X-Ray Interpretation	46
	Projections and the Normal Ray	46
	Interpretation of X-Ray Images	62
CHAPTER IV.	INDISPENSABLE X-RAY APPARATUS	68
	Means of Protection	68
	Radiographic Apparatus	68
	Apparatus for Conducting the Examination	75
	Accessory Material	88
	Biological Effects and Dangers of X-Rays	92

PAGE

CHAPTER V. SEARCH FOR FOREIGN BODIES. CONFIRMATION OF THEIR PRESENCE OR ABSENCE. CAUSES OF ERROR 99
History of Case and Clinical Examination 99
Undiscovered Projectiles. 100
The Radioscopic Examination . . 102
The Radioscopic Technique . . . 110
Radiographic Examination . . . 112
Result of Examination. 125

CHAPTER VI. PROJECTILES AND THEIR EFFECTS . 128
Infantry Projectiles. 129
Artillery Projectiles. 137

CHAPTER VII. GENERAL THEORY OF METHODS OF LOCALISATION 142

CHAPTER VIII. LOCALISATION OF PROJECTILES. . . 151
General Considerations: Historical Survey. 151
Radioscopy and Radiography . . 153

CHAPTER IX. LOCALISATION OF PROJECTILES (*Continued*) 173
Generalities on Localisation by the Double Image 173
Radioscopic Methods 175
Radiographic Processes 207
Practical Conclusions 230

CHAPTER X. RADIO-STEREOSCOPY 235

CHAPTER XI. ANATOMICAL LOCALISATION 249
Head and Neck 251
The Thorax 254
Diaphragm 261

PAGE

Abdomen 264
Spine and Pelvis 265
Upper Limb 269
The Migration of Projectiles. . . 271

CHAPTER XII. INDICATIONS AND CONTRA-INDICATIONS FOR THE EXTRACTION OF PROJECTILES. 273
Indications for Operation 273
Conditions Favorable for Extraction 275
Contra-Indications to Extraction. 276

CHAPTER XIII. PROCESSES OF EXTRACTION 284
Chance Processes. 284
Precision Processes 287
Processes of Certainty 295

CHAPTER XIV. SPECIAL PECULIARITIES OF CERTAIN REGIONS 327
Head and Neck 328
Thorax 336
Abdomen 343
Spine, Pelvis. 348
Limbs. 350

CHAPTER XV. THE SEARCH FOR PROJECTILES BY NON-RADIOLOGICAL METHODS . 358
Search for Magnetic Projectiles . 359

CONCLUSION 375

SECTION II
ARTIFICIAL LIMBS

BY

A. BROCA AND DUCROQUET

CHAPTER I. GENERAL CONSTRUCTION OF AN ARTIFICIAL LIMB 381

PAGE

CHAPTER II. GENERAL PRINCIPLES OF FITTING FOR THE LOWER LIMB 386

CHAPTER III. ARTIFICIAL LIMBS FOR AMPUTATIONS THROUGH THE THIGH 392
Apparatus with Bearing Upon Ischium 392
Mode of Suspension 401
Walking on a Peg Leg and Similar Appliances 408
Walking with Free Flexion of the Knee 413
Limbs with Bearing Upon the Ischium 440

CHAPTER IV. ARTIFICIAL LIMB FOR DISARTICULATION AT THE HIP JOINT 444

CHAPTER V. ARTIFICIAL LIMBS WITH FREE KNEE JOINT FOR AMPUTATION THROUGH THE LEG 446
Appliances with Bearing upon the Tuberosities of the Tibia . . . 447
Appliances with End Bearing Only 457
Appliances with Artificial Foot . . 460

CHAPTER VI. PARTIAL AMPUTATIONS OF THE FOOT 461

CHAPTER VII. ARTIFICIAL LIMBS FOR AMPUTATION THROUGH THE FOREARM 464
Points of Attachment 465
Elbow Joint 470
The Artificial Hand and Appliances 476
Appliances for Use in Place of Hand 488

CHAPTER VIII. ARTIFICIAL LIMBS FOR AMPUTATION THROUGH THE ARM 509

PAGE

Artificial Arm 512
Worker's Arm 518

CHAPTER IX. ARTIFICIAL LIMBS FOR DISARTICULATION THROUGH THE SHOULDER JOINT AND AMPUTATION THROUGH THE DELTOID 523

CHAPTER X. SOME GENERAL PRINCIPLES IN THE RE-EDUCATION OF THE DISABLED. 525

SECTION III

AFTER EFFECTS OF WOUNDS OF THE BONES AND JOINTS

BY

A. BROCA

CHAPTER I. DEFECTS OF BONY UNION. 541
Shortening and Angulation of Fragments. 542
Excessive Formation of Callus . . 550
False Joints and Loss of Bony Substance. 556

CHAPTER II. CHRONIC TRAUMATIC OSTEOMYELITIS 578
General Consideration of Osteomyelitis. 578
Amputation Stumps that Require Further Operation 582
Sinuses Resulting from Wounds of Bone and Compound Fractures. 602
Radiographic Study of Traumatic Osteomyelitis 619
CLINICAL STUDY 625

PAGE

CHAPTER III. THE TREATMENT OF CHRONIC TRAUMATIC OSTEOMYELITIS 648
Methods in which the Cavity is Packed with Organic Materials. 662
Methods in which the Cavity is Filled with Emulsions and Pastes of an Inorganic Nature. 668
The Technique of the Operation for the Obliteration of Cavities and Tunnels of Bone 678

CHAPTER IV. THE AFTER-EFFECTS OF WOUNDS IN JOINTS, MUSCLES AND TENDONS 707
The Pathological Varieties of Ankylosis, Stiffness and Deformity 708
The Treatment of Ankylosis and Stiffness of Joints 716
Preventive Treatment. 716
Curative Treatment 724

CHAPTER V. THE EFFECT OF MALUNITED FRACTURES ON THE ACTION OF NEIGHBOURING JOINTS 739
The Effect of Malunion on Hinge Joints. 742
The Effects of the Malunion of Fractures on Ball-and-Socket Joints. 751
Practical Conclusions.. 761

CHAPTER VI. GAS INFECTION AND GAS GANGRENE 763
Symptoms of Local Gas Infection. 764
Symptoms of Deep Gas Gangrene 764
Treatment. 765

PAGE

Indications for Amputation of an Extremity with Gas Gangrene . 767
Summary of Surgical Treatment in Gas Infection and Gas Gangrene 767
Antitoxin Treatment of Gas Gangrene 768

Poison Gases in Warfare ("Gassing") 769
Symptoms of "Gassing" 771
General Treatment of War Gas Poisoning 773
Treatment of Gas Collapse . . . 774
Local Treatment with Internal Oily Applications 774
Venesection in Chlorine Gas Poisoning. 775
Method 775
Prevention of Gas Poisoning. . . 776

Modern Treatment of Burns 777
Application of Ambrine. 778
Note by an American Editor. . . 778
Method of Treatment. 778
Liquid Paraffin. 784
Picric Acid 784
Chloride of Iron 785

Chapter VII. Some Medico-Legal Considerations. 787
Methods of Disposal of the Wounded After Cure 787
When Should the Patient be Regarded as Cured?. 790
Pensions and Gratuities 792
The Refusal of Treatment. . . . 799

PAGE

Instruction Relative to the Course of Action Necessitated by the Refusal by the Soldier of Treatment or Operation Recognized as Necessary 801

SECTION IV
WAR OTITIS AND WAR DEAFNESS

BY

H. Bourgeois and M. Sourdille

Chapter I. External Otitis 809
Acute Diffuse External Otitis . . 814
Induced External Otitis 816
Chronic Eczema 817

Chapter II. Acute Suppurative Median Otitis 819

Chapter III. Chronic Suppurative Median Otitis 823
Diagnosis According to the Stage and Extent of the Lesions . . . 831
Diagnosis of the Severity 834
Differential Diagnosis from Tuberculous Otitis 835
Therapeutic Indications 836

SECOND PART
WOUNDS OF WARFARE

Chapter IV. Wounds of the External Ear . 847
Wounds of the Auricle 847
Wounds of the External Auditory Meatus 849

Chapter V. Injuries of the Tympanic Membrane and of the Tympanic Cavity 851

PAGE
Etiology 851
Pathogenesis 852
Symptoms 856
Prognosis 861
Treatment 862

CHAPTER VI. WOUNDS OF THE AURICULO-MASTOID REGION 867
Etiology 867
Pathological Anatomy 868
Symptoms 870
Complications 872
Diagnosis 873
Treatment 874

THIRD PART

WAR DEAFNESS

CHAPTER VII. LABYRINTHINE CONCUSSION FROM DIRECT VIOLENCE TO THE CRANIUM 883
Etiology 883
Pathological Anatomy 884
Pathogenesis 886
Symptoms 888
Course. Prognosis 890
Diagnosis 890
Treatment. Course to Follow . . 893

CHAPTER VIII. LABYRINTHINE CONCUSSION FROM EXPLOSIONS 894
Etiology 895
Pathological Anatomy 897
Symptoms 899
Diagnosis 906
Treatment 910

PAGE

CHAPTER IX. DEAFNESS FROM LESIONS OF THE AUDITORY NERVE TRACTS. . . 916
Lesions of the Trunk 917
Bulb and Isthmus of the Encephalon 917
Cerebral Deafness 918

CHAPTER X. FUNCTIONAL DEAFNESS 921
Hystero-Pithiatism 921
Definition 921
Etiology 922
Clinical Description 925
Prognosis 929
Treatment 930
Simulation 934
Etiology 934
Symptoms and Diagnosis . . . 935
Course to be Followed 937

FOURTH PART

MEDICAL REPORTS 939

CHAPTER XI. PREVIOUS HISTORIES 941

CHAPTER XII. OBJECTIVE EXAMINATION 945

CHAPTER XIII. FUNCTIONAL EXAMINATION OF AUDITION 948
Preliminary Investigation of the Hearing for the Spoken Voice . 949
Measurement of Hearing-Power . 951
Hearing for the Spoken Voice . . 967
Cochlear Reflexes 972
Tests of Reliability 979

CHAPTER XIV. FUNCTIONAL EXAMINATION OF EQUILIBRIUM 996
Preliminary Examination 996

PAGE

Investigation of the Equilibrium when Standing Upright and Walking. 997

Search for Spontaneous Nystagmus. 1001

Induced Nystagmus. 1001

Babinski's Electrical Test 1016

CHAPTER XV. RESULTS OF EXAMINATION AND PREPARATION OF THE REPORT. 1024

CHAPTER XVI. LESIONS OF THE EAR AND MILITARY FITNESS. 1030

Fitness for Aviation. 1034

CHAPTER XVII. DISCHARGE No. 1 1036

INDEX. 1041

SECTION I

LOCALISATION AND EXTRACTION OF PROJECTILES

BOSTON MEDICAL
JUN 20 1918
LIBRARY

THE LOCALISATION AND EXTRACTION OF PROJECTILES

CHAPTER I

PRODUCTION OF X-RAYS

§ 1 **Tubes.**—Let us consider a glass tube similar to that shown in Fig. 1, into the walls of which metallic electrodes are sealed: one, the *positive*, called *anode*; the other, or

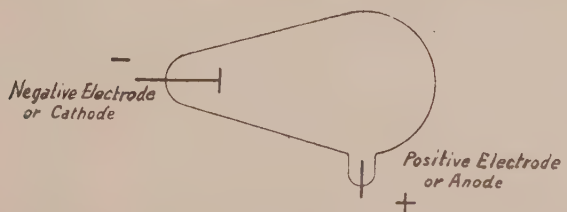


Fig. 1.—The X-ray producing tube in its original form, called the bulb or Crookes' tube. This is a simple glass tube of pyriform shape in which a very high vacuum has been produced, and in the walls of which are mounted two electrodes; one positive electrode or *anode*, and one negative electrode or *cathode*, terminating in a plate.

negative, being the *cathode*. Let us also presume that a very high vacuum has been produced therein.

By connecting (Fig. 2) the electrodes of this tube to the corresponding poles of some source of electric energy, we shall, if we have a source of high tension (of considerable voltage) at our disposal, *but only upon this condition*, succeed in causing it to be traversed by a current, whereas

the so-called low- or mean-tension currents are incapable of overcoming the resistance which it offers to their passage.

As long as the passage of this high-voltage current lasts, the cathode (negative pole) of our tube will throw off *electrons*—that is to say, what it is now agreed to regard as elementary masses of negative electricity (something similar to atoms of simple bodies but in miniature)—because the electron corpuscule (supposed to be real) is about 2,000 times smaller than the smallest atom; viz. the hydrogen atom.

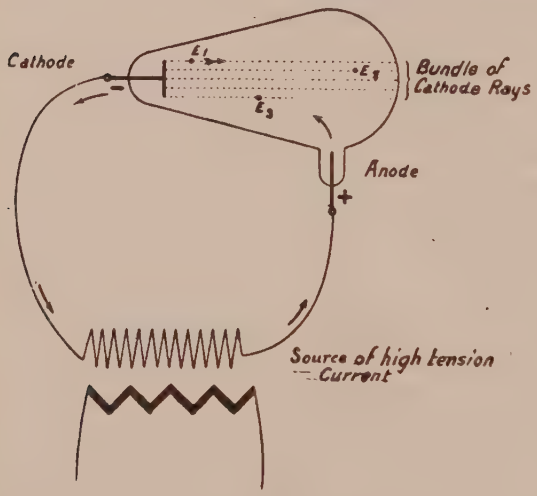


FIG. 2.—The anode of Crookes' tube is connected to the positive, and the cathode to the negative, pole of a high-voltage supply, the current of which circulates in the conductors and traverses the tube in the direction indicated by the four plain arrows. Its passage determines the emission at the level of the cathode, perpendicularly to its surface in the direction indicated by the barbed arrow, of elementary particles of negative electricity called electrons. They should be imagined as infinitely small spherules charged with negative electricity. E_1, E_2, E_3 are electrons shown at various points of their trajectory, which is designated as the *cathode ra* the whole complex of these *virtual* rays forming the so-called cathode pencil.

These electrons (which we may represent to ourselves, in order to materialise our ideas, as very minute—punctiform—spheres charged with negative electricity) are projected on leaving the cathode, at right angles to it, from their point of emission at a speed which increases with the difference of potential at the terminals of the bulb, or rather with the voltage at our disposal, and which

may attain a speed of 100,000 kilometres per second or one-third the speed of light.

If we have, as in Figs. 2 and 3, a cathode formed of a flat aluminium disc, a multitude of successive electrons will be continually emitted from it during the passage of the current through the tube, and the trajectory of each electron could be compared to a radiation termed the *cathode radiation*, the total forming a regular cone or sheaf of rays, viz. *the cathode pencil.*

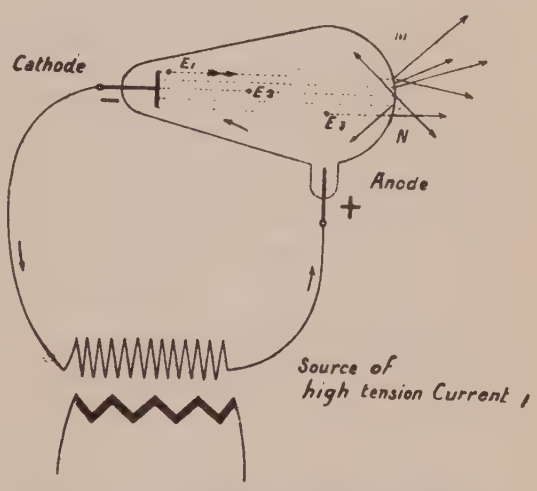


FIG. 3.—The electrons emitted perpendicularly to the cathode are arrested by the glass surface of the tube in the zone *MN*, which becomes the emission zone of the X-rays, as whenever an electron is suddenly arrested an X-ray wave is produced. These X-rays are thus emitted on the interior surface *MN*, and are diffused in a straight line in every direction starting from that surface.

Whenever the moving electrons are suddenly arrested in their course, X-rays will be produced at the stopping-point. This may also be expressed as follows: X-rays are produced whenever cathode rays come into contact with an obstacle.

The bulb or tube of the type shown in Figs. 1 to 3 was invented by the great English physicist Crookes (whence the name of Crookes' tube by which it is often known), to whom we have been indebted, since 1878, for his studies of cathode rays. In this type of tube the cathode pencil is arrested by the glass wall on which the X-rays are produced, the zone *MN* (Fig. 3) forming the source of emission.

But we have seen that the electrons might be likened to projectiles which, although very minute, are yet endowed with a formidable rate of speed. This velocity is such that,

assuming it to actuate a projectile with a mass of one milligramme, its sudden arrest would have the same effect as a collision with a fast thousand-ton train running at full speed.

It is, therefore, not surprising that the electrons or cathode rays (the two expressions may now be considered as synonymous) produce a considerable effect, and possess particular qualities. Thus every surface upon which they impinge is rapidly heated, namely, to such an extent that the glass wall of the bulb or tube receiving them is quickly melted. Owing to this important reason the construction of Crook s' tubes for the production of X-rays was soon altered, and another form adopted which was introduced in 1898 by the English chemist Jackson: since then it has remained the same with the exception of a few points of mere detail.

This new tube has been provided with a platinum sheet

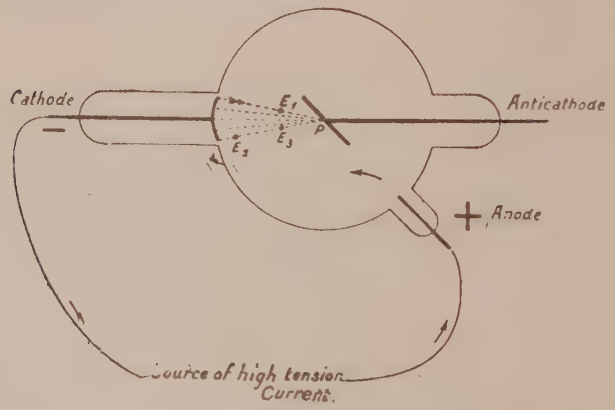


FIG. 4.—Crookes' tube modified by Jackson, similar to the modern form of X-ray tube. The cathode is concave and all the electrons E_1, F E_3 converge towards its focus on a level with which there is placed—opposite the cathode—a plate of platinum called for that reason the "anticathode." Hence it is on this that all the electrons are arrested and the X-rays are produced at the point P, called *focus* or *source*; from this point the rays radiate in a straight line in all directions as shown in the following figure.

in front of the cathode, this metal not being very fusible; hence the name of *anticathode*, and it is consequently adapted to receive the shock of the electrons (Fig. 4).

In this connection we must remember that there are two forms of electricity, viz. positive and negative electricity. By general agreement, fortunate owing to its simplicity, these are indicated by the corresponding algebraic signs + and −. It is, moreover, well known that electrical currents of the same name or sign repel, whilst of the opposite name or sign attract, each other. Thus two electrons which are two quantities of negative electricity —consequently of the same name or sign—repel each other. Numerous experiments have enabled the rather simple laws which govern the distribution of electricity over the surface of bodies to be determined. They constitute the principal domain of static electricity, and are applied to the distribution of charges of electricity over the surface and over the various parts of X-ray tubes.

Without having to quote these laws here it will be apparent from what has just been said that the anticathode must necessarily be considered as charged with positive electricity if it is desired that it should be able to receive and to attract the electrons which represent charges of negative electricity. The anticathode which receives positive electricity may therefore be considered as a positive electrode or anode.

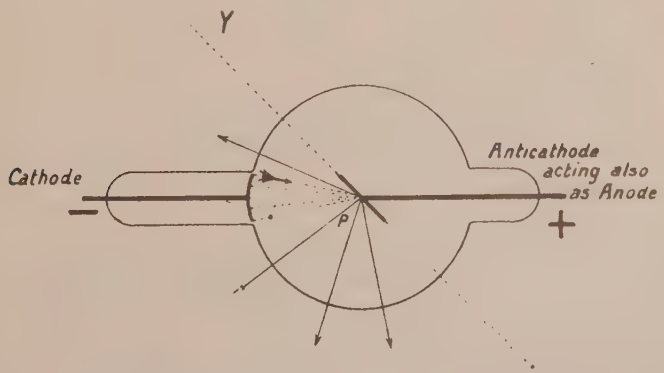


FIG. 5.—Production of X-rays. The cathode pencil converges on the anticathode at *P*. Starting from that point, X-rays pass in a straight line in all directions towards the plane *YX*, determined by the surface of the anticathode.

Tubes are in fact being constructed to comply with the scheme of Fig. 5, and in which the anticathode serves at

the same time as anode. Fig. 6 represents a type of the same tube of French construction. If in several other models manufacturers have preferred to retain one separate anode at the side of the anticathode, as shown in the tube in Fig. 7, this is mainly due to simplicity of construction, and care is taken to connect the two parts by means of a conductor when in operation.

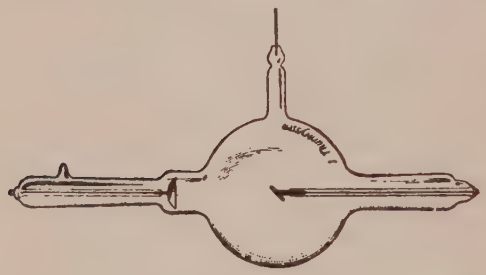


FIG. 6.—Chabaud tube in which the anticathode serves at the same time as an anode. This tube is provided with an osmo-regulator (p. 17).

But as the X-rays are to be utilised for radiodiagnostic purposes, as we shall see later on, in order to produce images by projecting shadows on to a fluorescent screen or photographic plate, the surface

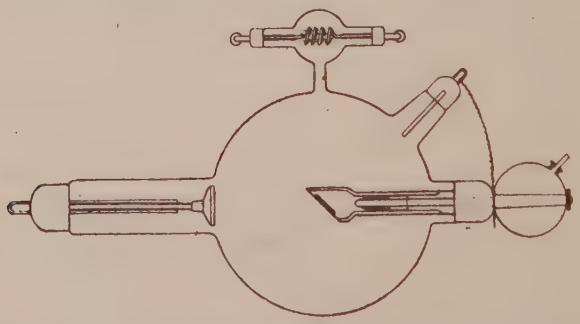


FIG. 7.—A Pilon tube presenting a distinctive anode and anticathode in which the cooling thereof is effected by a mass of water contained in a spherical reservoir, shown at the end of the neck of the anticathode. This reservoir is in direct contact with the metal extension of the anticathode, the surplus heat of which it thus absorbs by conduction. Should the water get warm it can safely be replaced by cold water, as the receptacle is of metal and consequently not exposed to breakage owing to the sudden change of temperature.

which produces them may be compared, as regards what follows, to a source of light. It is necessary therefore, if

we wish to obtain clear images without penumbræ, that this source should be punctiform, or at least greatly reduced in size as far as is practicable. It is therefore necessary that the surface which receives the pencil of cathode rays should be as limited as possible. By giving the cathode the form of a concave mirror, the cathode rays converge theoretically to form one focus.

If the metal plate intended to receive them (the anticathode) is adjusted to this focus we shall obtain a punctiform source of X-rays at this point of contact, or point of impact of electrons (Fig. 4 *et seq.*).

In practice this result is, however, never strictly realised.

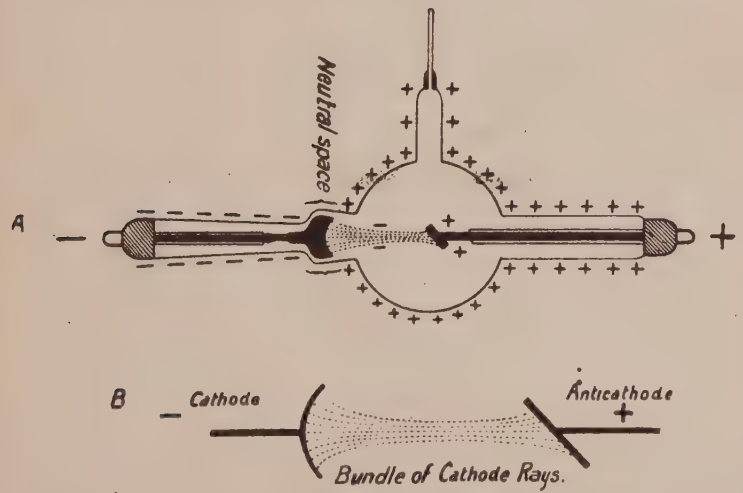


FIG. 8.—The purpose of this is to give a diagrammatic idea of the distribution of electricity over the surface of the tube *A* and of the approximate form *B* actually adopted by the cathode pencil. It will, however, be understood that this form can be modified according to the forces which act on the electrons, and especially if the voltage applied to the tube is varied.

The electrons are subjected, in consequence of the law which we have mentioned above (the attraction of electricity of a contrary sign, and the repulsion of that of the same sign), to the influence of multiple forces which induce them to deviate from their rectilinear path. The cathode pencil then assumes the aspect shown in Fig. 8, which corresponds more or less to the image of two curvilinear

cones much drawn out with their apices in contact, one of the bases corresponding to the cathode and the other and very much smaller one to the anticathode. The elliptical surface whereby the second cone is cut off upon the anticathode is still sufficiently small in well-constructed tubes to satisfy all requirements as to the clearness of the images.

Furthermore, if the zone of impact of the electrons were reduced too much, then the heating, which at this point is limited, would cause there the melting of the anticathode very quickly, however resistant to fusion the metal of which it is formed might be.

Finally, the glass tube has during this transformation become spherical as illustrated, and its term "bulb" or "tube" has remained only as a matter of habit. It is provided at the opposite ends of one of its diameters with elongated necks into which the electrodes are sealed. In order to avoid still further heating of the anticathode due to its being incessantly "bombarded," so to speak, by the electrons it is often made hollow, and is placed in communication with a water reservoir (Fig. 9) into which it is even possible to establish a water circulation; whereas in other types the cooling is ensured by a current of air. Since the time when it became possible to work tungsten, the platinum plate on which the focus emitting the rays is produced has been replaced by a disc of tungsten.

§ 2. **High-voltage Sources.**– We are provided with an X-ray tube which has a punctiform or at least a sufficiently small focus to satisfy our legitimate requirements with regard to the clearness of our radioscopic or radiographic images. As we have seen, in order to make it work and produce X-rays we must have a source of electric energy of high voltage.

Now, in practice we have only at our disposal currents of low or medium voltage (few volts), but of high intensity (many ampères), which the electric mains, generating sets (similar to those installed on several of the radiological cars belonging to the Sanitary Service), or at the worst accumulators provide. But if, in order to work our tube, we require a high tension (number of volts), that is to say a high voltage, then the intensity (number of ampères, or amperage in the language of electricians) required will be very weak, because it will not exceed 1 to 5 thousandths

of ampères (called milliampères or even, for brevity's sake, *millis*—a term which we shall hereinafter adopt) for most of the ordinary small installations. The larger installations, on the other hand, will need from 10 to 15 millis, and the most powerful plants will, in practice, hardly utilise for rapid radiography more than 20 to 40 millis, and quite exceptionally as much as 100 millis,* and then merely for periods amounting to fractions of a second.

We know that the product of the voltage is estimated by the intensity of a current; that is to say, the *product of volts by amperes*, which is expressed by a new unit

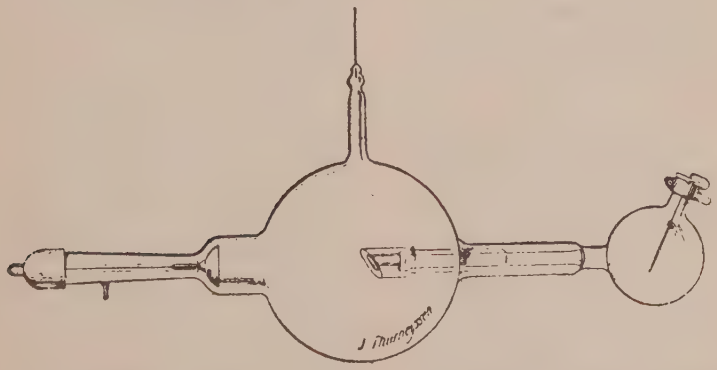


FIG. 9.—Chabaud tube with an anticathode cooled by direct contact with water.

called the *watt* representing *the power* of this current and *the electric energy* which it places at our disposal. This quantity of energy presents a maximum which it is not in our power to modify for any given installation.

On the contrary, it will be understood that we are at liberty to utilise it at our will in the form of low-tension current (low voltage), but of high intensity (high ampérage, or, *à fortiori*, milliamperage); or, on the contrary, in the form of current of higher tension (stronger voltage) and of weaker intensity (lower ampérage), or even in the shape of current of *high tension* (high voltage) of very weak intensity (*weak milliampérage*) on condition that the product of the volts by the ampères does not change.

* A meter device with direct reading, the milliampèremeter, measures momentarily this intensity in the high-voltage circuit.

We shall therefore have means of transforming the low-tension (up to 250 volts) and high-intensity current (up to 100 ampères) which is at our disposal into a current of very high tension (up to 100,000 volts and over) and very weak intensity (1 to 100 millis); the product of volts × ampères, that is to say the number of watts (the power) remaining of course invariable, subject to such losses as are caused by every transformation of energy.

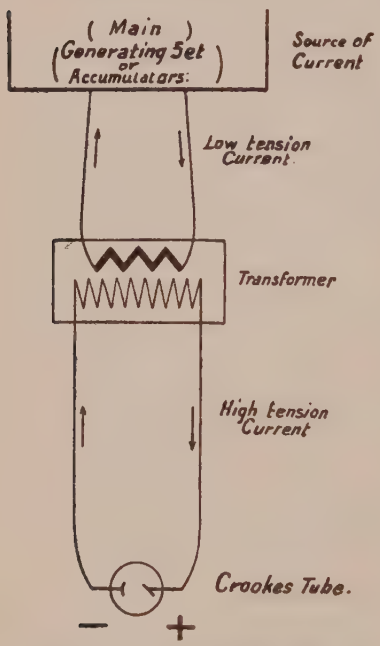


FIG. 10.—Complete plan of a radiological installation. An electric power station, a generating set or a battery of accumulators, is the source of electricity which gives us current of low voltage and high intensity to a transformer which passes a current of high voltage and weak intensity into the tube.

We are thus able to use at will either the electric energy placed at our disposal by employing 20 ampères at 110 volts or 0·020 ampère (20 milliampères) at 100,000 volts—not taking any waste into account in this *simplified* calculation.

The electrical industry to-day supplies us with a series of instruments for effecting this transformation, all of which are based on the principles of electromagnetic induction. These are either induction coils or transformers properly so-called. But our task is not to deal here with their theory, nor with the details of their construction.

Those interested in these matters should consult the works previously mentioned.

It is sufficient for our purposes to know that every radiological installation includes a source of high-voltage current—generally obtained by transforming the low tension, continuous or alternating current, supplied by

the mains—intended to excite the Crookes' tube which produces the X-rays.

But, as we have seen, this tube has well-defined poles. The current must, therefore, always traverse it in the same direction, or otherwise it will deteriorate very quickly.

Now these coils and transformers produce a "wave" or undulatory and alternating current. It is therefore necessary to use appliances which prevent the inverse wave from passing into the tube.

To achieve this it may be arrested and suppressed by mounting "cut-outs" in the circuit of the "Villard" valve type, which is an ovoid, elongated tube in which a suitable vacuum has been produced; hence owing to the special form of its electrodes it presents a very unequal resistance to the passage of the following current which has to traverse it in one direction or the other.

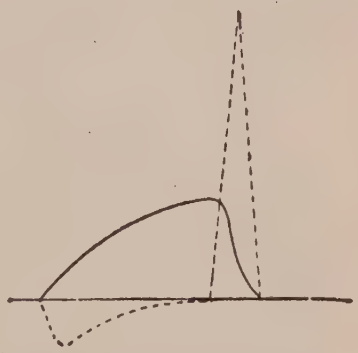


FIG. 11.—Diagrammatic curve of induced waves, the dotted lines representing the secondary voltage. The waves of high-voltage current, supplied by the coil or transformer, are projected into the tube circuit. The inverse wave is that which is shown below the horizontal line, and it is this wave which must be arrested or rectified as it would pass into the tube in an inverse direction; that is to say the cathode would serve as an anode and the anti-cathode as an anode. The electrons would then impinge upon the cathode. The full line represents the primary intensity.

It is mounted in the high-voltage circuit in such a way that the direct wave which should excite the X-ray tube easily passes it, but it arrests the inverse wave which would damage the tube. The two valves are generally mounted in the circuit according to the diagram shown in Fig. 13, which represents a different type from that of the preceding one. Unfortunately the valves are in themselves also Crookes' tubes, and as such they are exposed to the same inequalities of working and to all the annoyances attending adjustment. They will only be able to accomplish their task satisfactorily provided they be

kept in perfect working order, which necessitates constant supervision. In order to avoid the annoyance caused by the use of valves, it is possible to employ ingenious mechanical contrivances based on the principle of "rotary contacts" which enable the inverse wave to be "rectified"

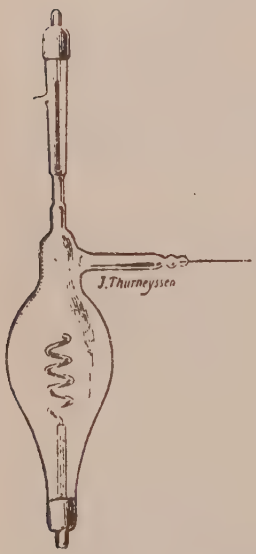


FIG. 12.—Villard valve. The current passes very easily if the top electrode be used as anode (+), but with great difficulty if employed as cathode (−), and if the current has entered through the lower electrode.

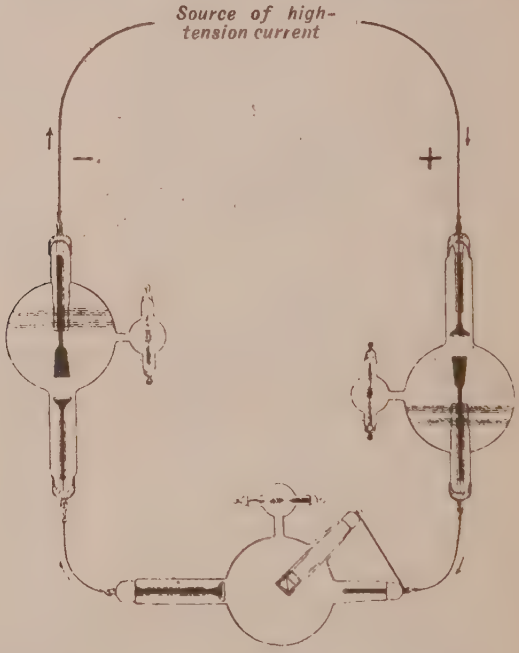


FIG. 13.—Diagram showing the reciprocal connections of the X-ray tube and the two valves intended to arrest the inverse wave and prevent its entering the tube (Pilon).

and passed through the tube in the right direction. Fig. 14 indicates what happens, and the means by which the "rotary contact" thus enables the two waves supplied by the transformer to be utilised, and this obviously considerably increases the yield.

§ 3. **Adjustment of the Tubes.**—Our installation is now completed. The *main* supplies us with any current

which we are able to transform into an alternating high-voltage current, and to send into the tube by causing it to be traversed by waves of the same direction only.

Let us now start our apparatus. The current, passing through, lights up the tube, and the whole half of the sphere, situated in front of the plane of the anticathode, becomes green with a beautiful fluorescence, provided the

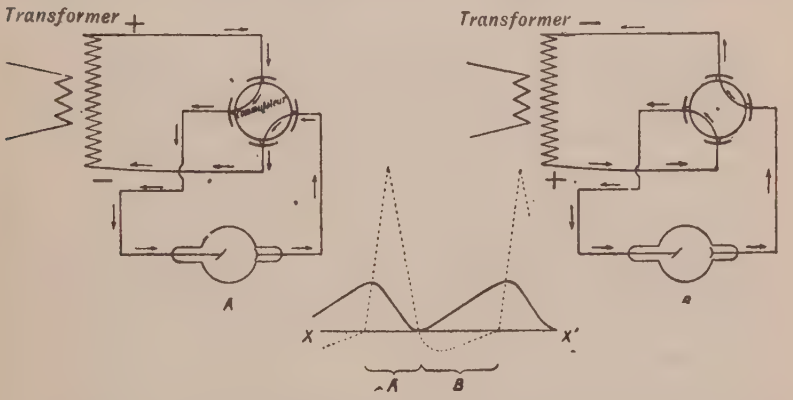


FIG. 14.—Diagram for rectifying the inverse wave by means of the rotary contact device. At *A* the circuit is traversed by the direct high-voltage wave in the direction indicated by the arrows. The commutator turns by one quarter revolution in synchronism with the alternation of the current. During the following period when the wave is inverted it will occupy the position indicated at *B*, and, owing to the change of connections thus produced, this inverted wave will still traverse the tube in the right direction.

connections be properly made (Fig. 15). If not, it will be immediately indicated by the appearance of the tube (Fig. 16), and the error can at once be rectified. Now how is this fluorescence produced? To say: "By the X-rays" would be the incorrect answer which is so very frequently given.

We must remember that, as the current passes, the electrons leave the cathode to impinge upon the anti-cathode. But at that point many of the electrons rebound in all directions and strike against the glass which they render fluorescent.

Let us bear in mind that when the current passes, the electrons leave the cathode to impinge upon the anti-

cathode, where, however, many of the electrons rebound from all sides and strike against the glass which they render fluorescent. The cathode rays (electrons) *which in themselves are invisible*, have the curious peculiarity

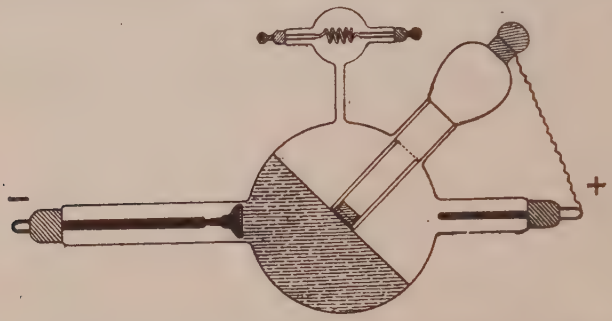


FIG. 15.—Tube working normally. The whole shaded part of the tube, that is to say the whole portion situated at the side of the cathode in relation to the plane determined by the surface of the anticathode, presents a beautiful uniform fluorescence, the colour of which will depend upon the composition of the glass used in its manufacture. Generally it is green, but with some glass of English make it is blue.

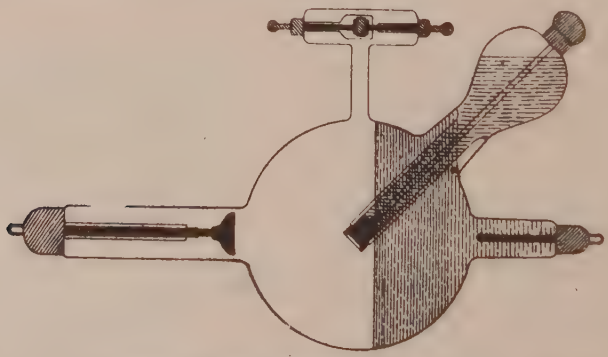


FIG. 16.—The same tube traversed by the inverse wave, or (what amounts to the same thing) wrongly connected up. The cathode thus serves at the same time as anode and as anticathode. It is therefore, on this cathode that the X-rays originate, and from it rebound the electrons which will make the walls of glass fluorescent when they are illuminated.

of rendering numerous substances fluorescent, such as glass (and consequently the glass walls of the tubes), and also most gases.

It is owing to this latter reason that in slightly exhausted tubes where the electrons still meet many gaseous molecules in transit and render them fluorescent, the passage of the cathode pencil is shown by a bluish luminous cone which is quite visible in darkness and can thus be studied very easily. It is evident that these electrons, when arrested by the glass walls of the tube, will produce X-rays, and this secondary radiation may become a source of trouble if it be too evident.

Our bulb was quite new; it showed bluish reflections, and even enabled the cathode pencil to be detected. It worked regularly and without noise at 2 milliamperes, and was easily traversed by the high-voltage current which excited it. We may say that it was *soft*, and that it produced mainly soft rays. But little by little the cathode pencil ceased to be visible, the bluish reflections disappeared, the green tint became modified, a peculiar crackling could be heard, and we saw the needle of the milliampèremeter gradually fall and commence to oscillate irregularly. The passage of the current became more and more difficult, and we may say that the bulb became *hard* As a matter of fact the internal condition of a Crookes' tube alters very rapidly when in operation. We have stated previously that a very high vacuum has been produced therein. This vacuum, however, is not perfect. The metallic parts which penetrate the interior of the tube, the electrodes and the anticathode (especially the latter), can evolve gases. On the other hand the glass walls, owing to complex phenomena the explanation of which does not come within the scope of this short summary, are capable of fixing and imprisoning the gaseous particles which they will no longer evolve. The state of the "interior atmosphere" of the tube will consequently be constantly modified during its working, the pressure being alternately increased or decreased.

If the tube runs at a rather higher pressure, or during a lengthy period, so that its anticathode becomes red-hot, then the metal will evolve gases, a part of which only will be reabsorbed by it when cooling, and another part will be definitely fixed on the glass walls. Hence it is only when we know how to regulate the working of the tube properly, so as to keep its degree of vacuum constant,

that we shall obtain satisfactory and constant results. Only an experienced technical man will be able to handle his tubes judiciously, and keep them in good working order for a long time. But in spite of all precautions, the tubes, with a few rare exceptions, will have a constant and increasing tendency to become *hard*, the more so if they have been used by inexperienced persons, as the walls will always absorb gaseous particles which cannot be released.

As this rarefaction increases, the working of the tube becomes more and more irregular and capricious; and, at last, there comes a time when the vacuum may be considered as absolute and the current entirely ceases to pass through it, and the tube then becomes useless. In order to remedy this defect, which is the principal cause of "breakdowns" and other troubles met with in the course of radioscopic and radiographic examinations, various appliances have been invented to enable gas to be introduced into the tube when necessary.

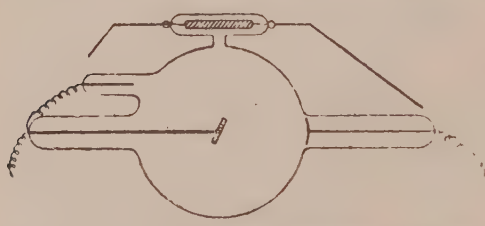


FIG. 17.—Tube with chemical regulator, operated by the passing of a current which evolves a certain quantity of gas from the substance used (mica, carbon, etc.). See also Figs. 7, 13, 16.

To do this, it is possible to attach to the tube a reservoir containing, for instance, some such substance as carbon or mica, which has the property of containing a large quantity of gas and of releasing it gradually when current is passed through it. These are the so-called *chemical regulators* (Fig. 17).

Another method consists of fitting to the bulb a small window of porous material, mercury-proof but not air-proof, and protected by a column of mercury. One stroke of a pump suffices to lower the column of mercury, which opens the porous window through which a little air immediately passes into the tube. Then the mercury rises again and the window is hermetically reclosed. The

strength and number of the strokes of the pump enable one to graduate the desired effect and to repeat it at will. This is the *air regulator* or Bauer regulator (Fig. 18)

Finally, perhaps the most perfect regulator is that based on the well-known property of platinum to become pervious to gas when it is red-hot ; this is the so-called Villard's *Osmo-regulator.*

It consists of a simple platinum tube, closed at its free end, the other end being sealed into the wall of the tube in such a way that its cavity is in communication with the interior of the tube.

Should the latter become too hard, the Osmo-regulator is heated by the flame of a gas jet or spirit lamp and is kept at white heat for a few moments

Under these conditions the hydrogen emanating from the gas or from the dissociation of the aqueous vapour in the hot part of the flame traverses the platinum, being attracted towards the more rarefied atmosphere, where it is retained as soon as the

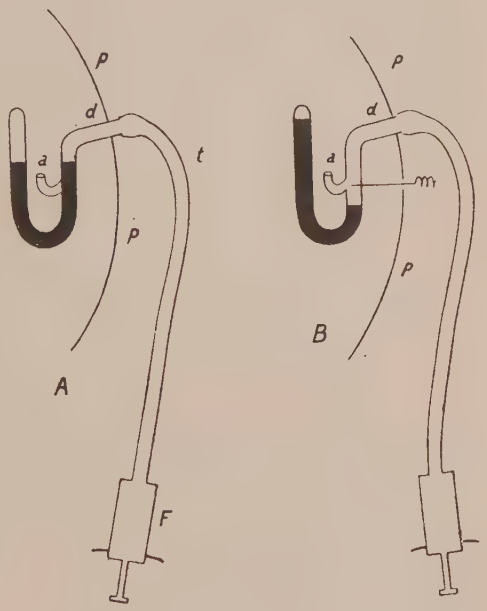


FIG. 18.—The air regulator. At *A* it is seen at rest. A U-tube is sealed into the wall (*p*) of the tube by means of a joint which enables it to communicate with the external atmosphere, and into which there is fitted the nozzle (*T*) of an air pump *F*. This U-tube has a small arm (*a*) open at the bulb end and is separated from the principal tube by a plate of porous material permeable to air. The U-tube is filled with mercury which shuts off communication between the tube and the external atmosphere. At *B* the apparatus is working. A stroke of the pump has driven back the mercury which uncovers the porous plate (*m*). The air then passes into the interior of the tube whenever and as long as this plate remains uncovered.

heating of the platinum has been discontinued, because the latter cools down almost immediately. Thus the vacuum in the tube may be lowered as often and as much as is necessary. For some years past palladium has been used in the manufacture of Osmo-regulators, this metal possessing from this point of view the properties of platinum to a still higher degree.

It must be pointed out that when the tube hardens, when working as we have indicated, and when the needle of the milliampèremeter indicates less current, this increase of resistance may nevertheless be overcome by increasing the voltage of our current. What takes place in such a case may be roughly compared to the effect obtained by forcing water under great pressure into a choked water-pipe in order to remove an obstruction. As will be readily understood it is therefore useful to know the voltage of the current and to be able to measure it. Although simple and handy instruments called voltmeters enable us to ascertain easily these data in the case of low-voltage currents, this is not the case with those of high voltage, and voltmeters which are used for measuring these high voltages are as a rule rarely seen except in physical laboratories.

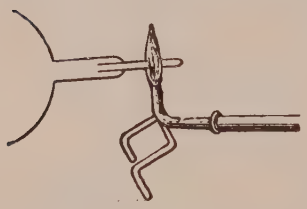


FIG. 19.—Use of the Osmo-regulator. Platinum heated red by the flame of a Bunsen burner or of a spirit lamp becomes permeable to hydrogen, and the gas attracted by the difference of pressure penetrates the tube. The tubes in Figs. 6, 9, 20 are provided with an Osmo-regulator.

Our measurement need not, however, be absolutely correct. What we require above all is a means to enable us to compare the voltages applied to our tube under various conditions; so as on the one hand not to reach the dangerous limits, and on the other hand not to make inferences from the indications thus obtained, as we shall see in the following chapter dealing with the properties of X-rays obtained under various conditions.

Now, if we assume that our tube is connected to the terminals of the high-voltage source by means of conductors, which are not provided with insulators, and if we bring

them in contact, there will come a moment when a spark will burst forth between the nearest points of these metal wires. We shall thus have caused what is known as a "short circuit"; this would mean that the resistance opposed to the passage of the current by the layer of air, which at this point is interposed between the two conductors, is less than the resistance of the tube. The current, always following the line of least resistance, is thus closed across the air in the form of sparks.

On regulating by experiment the gap which separates the conductors, we shall determine the exact distance at which the sparks are produced. At that moment the resistance of the tube is more or less equal to the layer of air which separates the conductors. The thickness of that layer or the length of the spark which will be produced at that level will give us the term of comparison we are looking for; this is what we call "the equivalent spark gap."

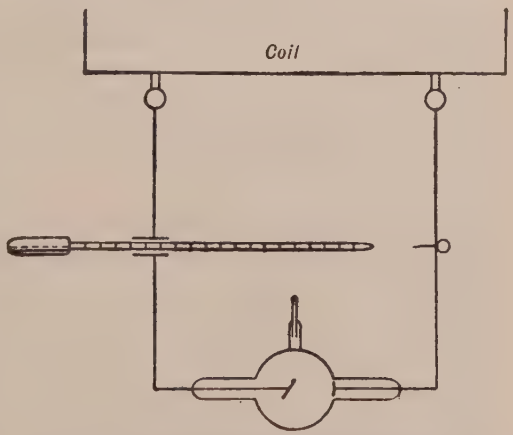


FIG. 20.—The Béclère spintermeter. The graduated bar is held by its insulated handle and pushed towards the opposite conductor until a spark is produced. If read at that moment the graduation will indicate the length of this spark in centimeters.

In order to simplify matters, Beclere has devised a sparking device graduated in centimeters mounted in circuit as indicated in the sketch, and which he has named the spark measurer or *spintermeter*.

The longer the equivalent spark, the greater, speaking generally, will be the resistance or the hardness of the tube, and *vice versâ*.

We have now obtained a tube such as may be seen to-day in most radiological installations, and in its simplest form,

in which the anti-cathode serves at the same time as an anode. In France it is represented by the excellent Chabaud tubes. These tubes are very strong and their output is relatively excellent. They are incapable, however, of standing the strong currents required for rapid radiography and of meeting the requirements of modern radiology. At the time when it appeared, this tube, the only one provided with a perfect regulating device (Villard's Osmo-regulator), was unequalled.

To its manufacturer it appeared to be so perfect that he remained deaf to all the requests of radiologists, who wanted to obtain more powerful tubes but had to be content with out-of-date material, or else to obtain tubes from German manufacturers. In this way the almost exclusive monopoly of this article, which could have easily been ours, soon passed almost completely into the hands of our enemies.

Only a few years ago a firm was established in France for the purpose of producing tubes capable of withstanding the highest voltages which would thus compete with German firms. This war has demonstrated that France has succeeded completely in this respect, and led us to appreciate the service rendered to the country by stopping (finally let us hope) the importation of this article.

French industry is now able to supply simple or high-power tubes which are equal, if not superior, to the best German makes.

American industry has also tried, before us, to shake off (at least partially) the German yoke, and even if some so-called American firms are nothing but poorly disguised branches of German industry, there are nevertheless some real American firms able to supply a really excellent article.

It is also from America that we get a new form of tube, the Coolidge tube, which in the near future will undoubtedly oust the present types almost entirely.

CHAPTER II

X-RAYS AND THEIR CHIEF PROPERTIES

Radioscopy and Radiography

Our apparatus is now in working order; current passes through the tube, which shows that beautiful uniform greenish fluorescence of its frontal hemisphere characteristic of good working.

The electrons coming from the cathode impinge upon the anticathode and the X-rays are produced at the point of impact. But, as already mentioned, they are not visible to the naked eye. It is only by observing their controllable effects, *i.e.* by becoming familiar with their properties, that we shall be able to ascertain how the tube is working, and make sure that they possess the necessary qualifications for the various uses to which we propose to apply them. We will, therefore, briefly summarise their main characteristics as far as is necessary for an exact comprehension of our subject. In other words, we shall limit ourselves to studying a few elementary considerations:

(1) The laws according to which these radiations pass through bodies.

(2) The characteristics which they possess: (*a*) of exciting fluorescence in certain substances, and (*b*) to having an effect upon "sensitised" or photographic plates. We shall deduce therefrom a few ideas necessary for the interpretation of radioscopic and radiographic images.

§ **4. Permeability of Bodies to X-rays.**—Everybody knows that various bodies are unequally permeable to luminous rays. Some, such as window-glass for instance, which we call transparent, allow them to pass almost entirely; whilst others which we call opaque, such as a piece of wood, stop them entirely. Between these two extremes

there are all the intermediate stages. In exactly the same manner, various bodies are very unequally transparent to X-rays.

But from our earliest days we have been accustomed to distinguish between bodies opaque or transparent to luminous rays, because these by acting on the retina are directly perceptible to our sense of vision. This difference in the quality of the bodies which surround us therefore appears quite natural to us owing to habit; but we are surprised to find that the same thing does not necessarily apply to the transparency of the same bodies to other radiations.

Thus two plates of an equal thickness, say 3 millimeters, one of crown glass, the other of flint,* have more or less the same transparency to luminous rays. But though the former allows X-rays produced by a Crookes' tube to pass almost entirely, the latter stops them almost completely. However, if we consider the matter properly, we find that these characteristics are not more surprising in one case than in the other: the surprise they cause is simply due to the fact that X-rays are invisible to the eye and that consequently we are not in a position to determine the transparency of bodies directly by our own unaided vision.

As a result of researches undertaken by the French physician Benoist, a law has been established which is essential to the exact understanding of all the medical applications of radiology, and it is of the utmost importance always to bear in mind that: X-rays as a rule traverse a body all the more easily if its atomic weight be less, but with more difficulty if its weight be greater. In other words, the *X-ray transparency of various bodies stands in inverse proportion to their atomic weight.* Thus, a thick oaken board if interposed between the tube in action and the fluorescent screen will produce only a very faint shadow whilst a thin sheet of lead will entirely obscure the luminous surface.

Atomic weight being equal, it is only the number of atoms (that is to say solely the thickness of the body)

* Window, Bohemian, and bottle glass are light glasses and transparent to X-rays; crystal and strass are heavy lead glasses impermeable to X-rays.

that interferes with the passage of the rays; and the shadow given by an iron plate of 2 millimeters will have roughly, double the intensity of that obtained by a 1-millimeter plate.

But if we consider the X-radiation emitted by a tube in action, and if we examine its penetrating power as regards a given body, of a certain determined thickness, we shall soon find that that quality will vary considerably every moment according to the state of the tube. At one moment the radiation will be stopped almost entirely by a thin sheet of lead, say a tenth of a millimeter thick; at another it will, on the contrary, penetrate it to a great extent and will even illuminate the screen after having traversed it. In the first case we say that the radiation is soft or of slight penetration; the tube will at that moment be soft, and its equivalent spark will be short, that is to say the difference of potential at its terminals (or the voltage applied) will be small.

In the second case the radiation will on the contrary be called hard or penetrating, and the bulb at that moment will be hard, the equivalent spark will be long, and the difference of potential at the terminals (or the voltage) will be great.

As already stated (Chapter I, § 1), X-rays are produced when the electrons, moving at high speed, are suddenly arrested. If we consider X-rays as being of the same nature as luminous rays—a comparison which, considering everything, we are now not only authorised, but even obliged to make—we must admit that they are electromagnetic vibrations of the ether. These vibrations are created when the electrons are arrested and, as will be readily understood, they may be different in their intensity and consequently also in their physical qualities, according to the speed of the electrons which produce them: that is to say according to the force of the impact.

Now, this speed of the electrons depends entirely upon the difference in potential at the terminals of the tube, and varies in proportion with the latter. The relationship previously explained is thus made clear, and practice enables us to observe daily that the harder the tube (that is to say the higher the voltage of high-tension current which traverses it) the harder or more penetrating are

the X-rays produced (the term "penetration" and "hardness" may be considered as synonymous).

Let us now consider a point where an electron is suddenly stopped and starting from which an X-vibration is going to be produced. From the point of emission or the centre of propagation of the X-radiation, there starts a series of waves which extend equally in all directions at a uniform speed equal to that of light. In order to simplify matters, let us consider it from one standpoint only. We shall be able to obtain a concrete idea by comparing them with the phenomena of the undulation of water and by bearing in mind what happens on a liquid surface into which a body has been dropped. From the point of contact with the liquid surface, there starts a series of waves or undulations which form round that point concentric circumferences of increasing radius. These waves of the liquid surface succeed each other; each one is separated from that following by a depression, the depth of which is equal to the height of the wave (Fig. 21).

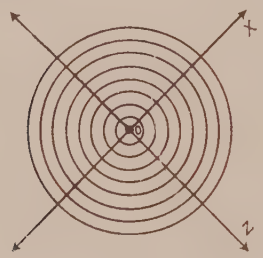


FIG. 21.—This figure represents a diagram of the waves which spread concentrically in every direction, *OX*, *OY*, etc., on the surface of a sheet of liquid, starting from falling-point *O* of any body. These waves may be likened to those which would be produced by luminous vibrations or X-vibrations if they were considered in a single plane only.

Let us imagine what happens along any X-ray *OX* of these concentric circumferences. A very correct idea of the undulatory movement in this respect will be obtained by comparing it to the coiling of a cord fixed at one end, the other being held in the hand and briskly moved to cause rapid undulation (Fig. 22).

Geometrically, the representation of the process following the ray *OX* is supplied, as we know, by a curve like *OX* called sinusoidal (Fig. 23). On this curve distances, such as *OB*, measure *the length of the wave* or radiation under consideration.

From the physical standpoint this length of wave serves to characterise a radiation and determines its properties. Two radiations of an equal length will be identical as regards their properties and their effects; more especially

FIG. 22.—A cord is fixed at one end *D*, and if the other end *C*, held in the hand, is moved briskly up and down, a serpentine movement is produced which will give an idea of the undulatory movement of Fig. 21 if we regard it for instance as following the ray *OX*.

as X-radiation with a given length of wave will always have the same penetrating power as regards different bodies.

Thus, the various electro-magnetic vibrations which constitute heat, light, and the invisible rays of the spectrum should be defined by the length of wave, in the same way as X-rays and rays of radio-active substances.

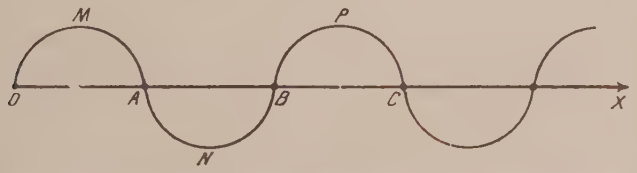


FIG. 23.—This curve, called *sinusoidal*, is a geometrical representation of the vibratory movement caused along the ray *OX*. The portions *OMA*, *ANB*., etc., of the curve are called loops; the points *A*, *B*, *C* the nodes of the vibration. The curve *OMN* is a complete wave and the cord *OAB* the *length of the wave*. The "loops" are here incorrectly shown as arcs of a circle.

The following table indicates the wave lengths which include the principal known radiations:

Character of the Radiations.	Length of Wave.
Hertzian waves . . .	From 10,000 meters to 6 millimeters.
Caloric waves (ultra-red rays)	From 00,3 to 0,00008 cm.
Luminous rays (visible spectrum)	From 0,00008 to 0,00004 cm.
Ultra-violet rays . . .	From 0,00004 to 0,00001 cm.
X-rays	From 0,00000005 to 0,000000001 cm.
X-rays	From 0,00000002 to 0,000000001 cm.

Sometimes, in order to avoid an alignment of useless figures, the wave-lengths are expressed in μ or the thousandth part of a millimeter, and in $\mu\mu$ for a millionth part of a millimeter.* Thus it is the wave-length which finally characterises all radiation, X-radiation in particular, and which determines its quality. The shorter the wave-length, the greater the penetrating power of the X-radiation is considered to be. Or in other words, *the shorter the length of the wave of an X-radiation is, the greater is the velocity of the electrons which produce it.*

This is an aspect which interests us to a great extent because upon it depends largely the quality of the radioscopic and radiographic images we shall now have to examine, and their value from the radio-diagnostic standpoint. It is therefore necessary to be able to estimate and measure it.

But in practice we are not trying to measure the wave length of the radiation under consideration. The methods which would enable us to determine this would necessitate complex manipulations and instruments. Only well-equipped physical laboratories are now able to obtain these data. Moreover, all tubes now used yield electrons of very different speed. On being arrested, they would yield X-rays of different wave-lengths, and the radiation produced would consequently always form a complex sheaf, comparable with the complex and polychromatic pencil of white light, and never a radiation of a single length of wave comparable to a simple monochromatic radiation.

In order to estimate the quality of X-radiation we shall use the *Radiochromometer*, a very simple and ingenious instrument invented by M. Bénoist. Its use is based upon the following theoretical considerations.

Certain bodies, such as aluminium, do not retain the same transparency to X-rays according as to whether it is a question of soft rays (great wave-length) or hard rays (short wave-length). If, for instance, a 1-millimeter

* Physicists employ the C.G.S. (centimeters, grammes, seconds) system and note the subdivisions of the centimeter in powers of 10 with negative sign. Hence: 1 mm. $= \frac{1}{10}$ cm. $= 10^{-1}$ cm. 0,0000000017 cm. will be described as $1{\cdot}7 \times 10^{-10}$ cm.

aluminium plate arrests 80% of a soft radiation which falls on it, it will not check more than 25% of a very hard radiation.

In other words, if a 1-mm. aluminium plate interposed between the tube and the screen produces with the first radiation a shadow of a certain intensity, it would be necessary with the second type of radiation to interpose for instance a 7-mm. aluminium plate in order to produce the same shadow intensity.

On the other hand other bodies, such as silver, present more or less the same transparency (physicists call the same "*radiochroism*" —a term which they have given to that particular property which is said to be the cause of the difference in transparency of coloured screens in the case of certain monochromatic lights) for all kinds of radiation.

Thus a 1/10-mm. silver plate which arrests 40% of a soft radiation falling on it will also check 40% of all other kinds of radiation; that is to say nearly half of all the X-radiations, of whatever wave-length (Fig. 24)

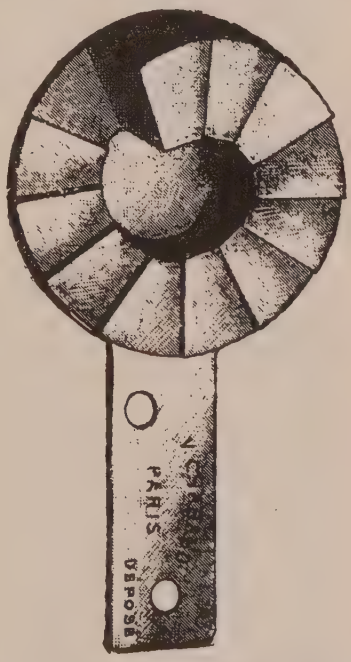


FIG. 24.—The Benoist Radiochromometer, actual size. Note the arrangement of the aluminium sectors of increasing thickness which surround the thin silver plate.

On comparing the relative transparency of aluminium in relation to that of silver for a given radiation, we shall have an easy means of estimating its quality; this will be our procedure on using the radiochromometer. This apparatus, shown in Fig. 24, is formed by a series of 12 aluminium steps, the thickness of which increases gradually from 1 to 12 mm.; they are arranged in the same way as the figures on the dial of a watch. These

sectors leave in the centre a circular space in which is mounted a thin silver disc, 0·11 mm. thick.

In order to use it, it is placed against the fluorescent screen on the side nearest to the tube.

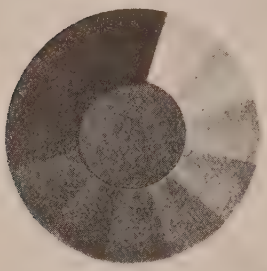


Fig. 25.—This radiograph of Benoist's radiochromometer has been taken with No. 7 rays. We are able to distinguish very clearly the increasingly intense shadows of the six first aluminium sectors. The shadow of the seventh sector is clearly seen, and shows the *same intensity as that of the silver disc*. The average quality of the pencil of rays used was thus of a No. 7 Benoist radiation. The following sectors, from the eighth to the twelfth, have been traversed by a very small number of rays only. They give an intense and almost uniform shadow.

It will then be seen that each aluminium sector produces a shadow of a different intensity. Amongst these shadows there is one the intensity of which may be considered equal to the shadow of the central silver disc which is used for comparison. If, for instance, it is the shadow of the seventh sector, then we say that the rays used are 7 degrees Benoist. It is, however, generally preferable to take a radiograph of the radiochromometer, as this allows a more precise comparison. Fig. 25 shows such a radiograph.*

As correctly expressed by Jaugeas in his excellent handbook, the radiochromometric degree does not absolutely express the power of penetration of the radiation emitted by a tube; because it consists of sheafs of rays of unequal penetration. When we say that the tube emits No. 6 rays, this figure indicates only the average value of the power of penetration of the sheaf emitted at that moment; that is to say that besides No. 6 rays there are for in-

* Various modifications of the Benoist apparatus have been produced, but seem to be only useless complications. The only one worth preserving is the device invented by J. Belot, called the Penetrometer, owing to the advantages it offers when it is desired to follow the variations of the quality of a tube which works in daylight or in a lighted room.

stance No. 4, 5, 7, 8, etc., rays, but in a lesser quantity, and the degree 6 is the resultant of the radiochromometric degrees of the various constituent pencils of rays.

§ 5. **The Screen and the Fluoroscopic Image.—Radioscopy.**—The property possessed by X-rays of rendering certain bodies fluorescent, the principal of which (from the standpoint of practical application) is *platinocyanide of barium*,* is the starting point of *radioscopy*, sometimes still called *fluoroscopy*.

A sheet of cardboard (or of any other substance of low atomic weight, such as wood fabric, etc.), covered with a thin and equal layer of platino-cyanide of barium, and exposed to the pencil of X-rays emitted by a tube, will become illuminated equally, and the more abundant the radiation falling upon it is, the more vivid is the illumination.

If we interpose different substances between the source of the rays and the illuminated screen, they will project on to the screen *a shadow, which will be all the more opaque the less permeable such substances are to the X-radiations* of which they will, consequently, intercept a higher proportion.

Various organs and various tissues of the human body are, however, according to their thickness and their chemical composition, very unequally permeable to X-rays. Interposed between a source of these rays and a screen covered with fluorescent substance they give rise to shadows of unequal density on the illuminated surface due to these invisible rays.

These shadows, which are known as Chinese Shadowgraphs and which present such great similarity to these images, are only transmitted shadows and are formed by the interposition of opaque bodies between the luminous focus and a translucent screen. If they were nothing more, if they projected only the exterior outline of objects giving a uniform shadow, then the images supplied by X-rays would be of little interest. They are fortunately much more complex; they are superimposed shadows of different densities. For a long time almost all the fluores-

* Amongst the other fluorescent or phosphorescent bodies influenced by X-rays, and offering a practical interest, we may mention *sulphide of zinc* and *tungstate of calcium*.

cent screens used in medical practice were of German manufacture; then screens of British make appeared on the market. Finally two French firms, Roubertie and Caplain-Saint-Andrée, were able to produce screens which could compete successfully with those from abroad. Since the war they have not only greatly developed their output, but also perfected their manufacture to a considerable extent; their screens very successfully replace the best German makes which will now be no longer required.

The illumination of a screen is very variable and depends on conditions which are governed either by the screen itself or by Crookes' tube, or else by the respective distance and situation of the tube and of the screen.

All screens covered with platino-cyanide of barium do not become equally luminous under the influence of the same excitation.

There are in this respect great differences between the screens; these are due either to the conditions of the salt, its purity, etc., or to other complex questions with which we shall not deal here. The fluorescent power of screens also decreases gradually with the duration of their exposure to X-rays, or may even disappear completely under the influence of too great heat.

The same tube at the same distance from the screen will illuminate it quite differently according to the quantity of radiations produced. All other things being equal, the greater the quantity of the rays produced the more vivid is the illumination of the screen. In the same way, all other things being equal, *the illumination of the screen depends upon its distance from the tube.*

The action of the X-rays, similarly to that of light, heat, and of all other radiations, *varies in inverse ratio to the square of the distance.* A screen which shines with a certain brilliancy at a given distance from the focus emitting the rays shines at double the distance with four times less brilliancy; and at triple the distance its brilliancy will decrease nine times. Moreover, the various parts of the screen are unequally illuminated, if struck more or less obliquely by the divergent pencil of rays emitted by the focus.

These are the principal conditions which cause a variation in the physical and objective character of visible radia-

tions supplied by the screen, without considering the luminous sensation provoked by them.

It is with the latter, the action of the eye in front of the fluorescent screen, that we have now to deal. This study is of great practical interest, because the unjustified limitation in the use of radioscopy in medical radiology and particularly in war radiology dealing with the finding of projectiles is due principally to a misunderstanding of the elementary rules resulting therefrom. These studies were made by Mr. Béclère at an early stage of the development of this new science in such a masterly way that the years which have elapsed have changed nothing in his conclusions and have added very little thereto. The following passages have been taken almost literally, as was also the case with the first part of this paragraph, from the remarkable treatise which he himself has written on that subject.*

§ 6. **The Visual Function in Radiology.**—The sense of sight enables us to perceive light, colours, and forms. The perception of light and form are the only questions to be considered for a radioscopic examination. They must be carefully separated from each other: they correspond, at least apparently, to two different functions of the retina.

Thus the physiology of vision includes in radioscopy on the one hand the sensitiveness to light supplied by the fluorescent screen, viz. the *luminous sensitiveness*; and on the other hand the ability to distinguish between the limits and the outlines of various unequally luminous portions of that screen; this is generally called *visual acuteness*, or sometimes, *proper visual sensitiveness* (Charpentier). It is useful to add the examination of a phenomenon which is of some importance when dealing with radioscopy; this is the persistence of retinal impressions.

Luminous Sensitiveness.—Everybody knows that after staying for some time in the dark the eye is capable of appreciating a feeble intensity of light which at first leaves it entirely unaffected. This phenomenon plays a very important part in the study of radioscopy. If the apparatus which produces the X-rays is not very powerful

* A. Béclère: *Traité de Radiologie Médicale de Bouchard*, Paris, Steinheit, 1904.

and if the obstacle interposed between the tube and the screen is a rather large thorax of an adult, the person coming from broad daylight into the dark room where the experiments are conducted is always surprised to perceive only a very slight glimmer emanating from the screen without being able to distinguish any image on its surface; whilst observers who have entered the room earlier are able to distinguish moving images such as the beating of the heart and the movement of the diaphragm. A few minutes' patience will enable the new-comer to perceive that the screen begins to get luminous and soon more and more brilliant. He then sees the images which were visible to his predecessors; soon the light of the screen will enable him to distinguish the persons and objects that surround him, and very often he will even discover that numerous cracks allow daylight to penetrate into the room which at first seemed to be dark.

This well-known occurrence is generally explained by saying that it takes some time to get used to darkness; but this is not an explanation. The truth is that these variations in luminous perception obey a very important law, which is called *luminous adaptation*.

The minimum of light perceptible to the same eye is very far from being definite, but changes practically every minute; its value depends upon the average light to which this eye is subjected and adapted.

The stronger the light the higher the perceptible minimum; that is to say, the weaker the luminous sensibility. On the contrary, the weaker the light becomes, the higher the decrease of the perceptible minimum; that is to say, the higher the increase of sensitiveness. If the eye passes from light to darkness, the perceptible minimum decreases with a speed which follows more or less the same law as that of the cooling of bodies. Dr. Parinaud has particularly studied under the name of "adaption to darkness" the increase of sensitiveness resulting from the eye being in darkness for about twenty minutes, and he has noticed that the increase is not the same for the different parts of the solar spectrum. *This increase seems to be slowest in red and quickest in violet light.* Owing to this special faculty of the eye we can see fairly well relatively feeble twilight, moonlight, or artificial light that

illuminates the streets. The light emanating from the fluorescent screen is similar to the lights just mentioned, a light of low intensity. There is no doubt, and the simplest observation will prove it, that the adaptation of the eye is an important factor in radioscopic examination and plays a very important part in connection with it. In order to determine this, Mr. Béclère has conducted a series of experiments with his pupils, the principle of which was as follows: The illumination of the screen varies, other things being equal, according to its distance from the tube. The luminous sensitiveness of the various observers is compared by ascertaining, in each case, the distance of the tube at which the fluorescent screen gave the observer the minimum of perceptible light. In any case the degree of sensitiveness which it is desired to find is proportionate to the square of the distance measured from the tube to the screen. These experiments have made it possible to gauge the importance of the adaptation of the eye to radioscopic examination. They have demonstrated the instability of luminous sensitiveness, which varies incessantly according to the receptivity. In view of this instability the figures supplied would not be of absolute value. Such as they are, however, they give an idea of the enormous difference that exists in front of the screen between the retina which is not, and which is, receptive; and also of the almost incredible increase of sensitiveness which is supplied to the retina by a few minutes' observation. *We may say, speaking in a very general way, that under the conditions mentioned the luminous sensitiveness becomes, after a ten minutes' observation,* 50 *to* 100 times larger, and that after a twenty minutes' observation it *becomes* **200 *times larger than at the moment of leaving broad daylight. It increases even after the lapse of that time.***

The comparative study of the individual variations of retinal sensitiveness also supplies other very interesting data. To start with we see that apparently under equal conditions sensitiveness to the light of the screen varies to a great extent with different persons leaving broad daylight. With some it may be four times larger than with others. We see that this degree of increase in luminous sensitiveness may vary, in the course of adapta-

tion, from one day to another with the same person under the influence of diverse conditions, such as fatigue for instance.

Finally, whilst bearing in mind these daily variations we see that a permanent inequality exists amongst the various persons whose receptivity we are studying; and that some of them possess a marked superiority over others, amongst whom only those suffering from night-blindness show an inferiority which is sufficiently considerable to be considered a inhibitory defect from the radiological standpoint.

It is hardly necessary for us to point out the practical consequences resulting from the foregoing conclusions from the standpoint of the darkness of the room, of the necessity of excluding the luminosity of the tube by a black covering, of avoiding sudden penetration of light, etc.

§ 7. **Action on the Photographic Plate; Radiography.**— X-rays act upon the coating of photographic plates in the same way as luminous rays. If therefore we substitute a layer of sensitive gelatine for the fluorescent screen we shall obtain by submitting it after proper exposure to X-rays to the usual photographic manipulations (developing and fixing) an image or *radiograph* which will be an exact materialisation of what appeared on the fluorescent screen. We shall thus have fixed on the plate in their relative intensity the complex shadows which show the difference in transparency to X-rays of the constituent parts of the objects or of the parts of the body interposed between the source of radiation (the tube) and the plate.

It must of course be understood that as in the ordinary photographic process the plate obtained will be a *negative*. The parts which are opaque to the rays, that is to say the dark parts (such as bones, projectiles, etc.) will appear thereon in white, and the transparent parts, such as flesh, in black (with all the relative intensities of white or black, according to the opacity or translucency of the parts affected by the rays). Then by transferring this plate or negative to paper we shall obtain the reverse, that is to say the *positive* in which the opaque parts will be black and the transparent parts light (see Figs. 27 and 28). We are often too apt to forget that radiographs have nothing in common with ordinary photographs except the

treatment of plates by developing and fixing baths, etc., but that with the exception of this resemblance in their manipulation the images obtained differ essentially. Whereas photographs give us the exterior form of objects transferred to the plate by means of a lens, and in general with a considerable reduction in size, radiographs are simply and exactly (like X-ray images on the fluorescent screen) projected and generally enlarged shadows which give us not only the projection of an obvious external outline apparent to the eye, but also details of internal structure based on differences in chemical composition (differences of atomic weight) which are not otherwise apparent.

Hence while in a general way properly speaking no interpretation of an ordinary photograph is necessary because everybody understands it perfectly by looking at it and knows what it represents, quite the opposite happens in the case of a radiograph, where the interpretation is everything and the aspect of which reveals nothing or practically nothing to the uninitiated. In other words we must be able to read a radiograph; and whilst it is clearly evident that in order to apply radiology medically it is absolutely essential to be a physician and an anatomist if the reading is to be correctly made, still this is not in itself sufficient, and in order to interpret them correctly we must *constantly bear in mind* certain conditions under which the images have been obtained, otherwise mistakes may be made in reading which would have bad consequences to wounded and sick patients.

We must therefore strongly advise physicians and surgeons who examine radiographic proofs to get accustomed in doing so to observe certain rules to which they will conform later on naturally and to a certain extent automatically; we are sure that by so doing they will avoid many disappointments and mistakes which might have very annoying consequences which occur daily in too many cases. They will moreover gain thereby full confidence in their readings of the plates and will not feel hopelessly bewildered even if they do not have the assistance of a professional radiologist.

§ 8. **Examination of Radiographs.**—When we examine a radiograph of any part of the body, for instance a shoulder,

without any further indication as to the side from which it was taken, the first question that arises is whether we are dealing with the right or with the left side. Without some precise rule for examining plates this question cannot be solved. According to whether we examine the radiograph from its glass or from the coated side, so may we assume that we see either a right shoulder viewed from the back, or a left shoulder viewed from the front, or else either a right shoulder seen from the front or a left shoulder seen from the back. Technical reasons and well-established customs in the way in which negatives are taken enable us, as a rule, to eliminate as far as a shoulder is concerned the hypothesis of a front view. Moreover, the appearance of the images would not in this case be absolutely identical, and with a little experience it will be possible easily to distinguish from which side the radiograph has been taken (Chapter III). But between the two alternatives of a right or left shoulder seen from the back according to the side of the plate examined it would be impossible to give a correct opinion.

FIG. 26.—Tracing taken on the screen of a radioscopic image of the right shoulder (seen from back), the patient looking at the tube. Projectile in axilla.

In order to settle all these difficulties we recommend a method which always remains the same and is apparently the simplest and the safest. This consists in taking radioscopy as our basis for guidance.

Let us take the case considered above, namely the shoulder, and let us assume that it is the right shoulder.

If we wish to examine it radioscopically we must place the subject facing the tube, his back towards us, and the screen on which the image shown in Fig. 26 will be

produced is then applied *in situ*. If we now take a radiograph of the same shoulder we have simply substituted a plate for the screen. During the pose the sensitive layer applied to the shoulder is turned towards the tube. If after developing and fixing it we look at it from its glass side by turning the gelatine towards the light the image will be seen as shown in Fig. 27, with exactly the same orientation as the radioscopic image of Fig. 26. If therefore ignoring the film side we examine any plate of a shoulder by viewing it from its glass side, it will be sufficient to imagine that we are making a radioscopic examination, that the subject is situated between the luminous source and the operator, and that the plate takes the place of a screen, whereupon we shall immediately ascertain the correct position. This can of course be applied indiscriminately to any part of the body.

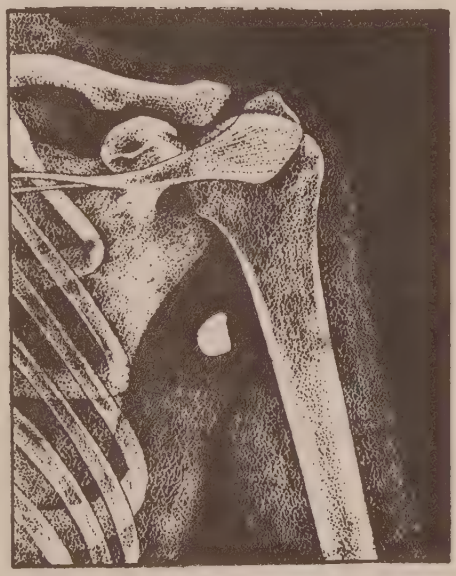


FIG. 27.—Radiograph of the right shoulder. The patient has a metallic foreign body present. This is a negative plate viewed from its glass side. This image is seen in exactly the same way with the exception of details as the radioscopic image of the preceding figure.

If we now have before us a proof on paper of a positive of our plate as shown in Fig. 28, the same remarks will be applicable to it; in order to ascertain the correct position we simply have to consider it as if it were a projection of an X-ray image on the screen. Thus the fluoroscopic image,* the radiographic plate, the positive proof, all the X-ray

* The same considerations apply, of course, to tracings taken from the screen or from the plate.

evidence will be examined in the same spirit and will supply the information desired. This visualisation of images which at the beginning requires a slight effort soon becomes automatic and almost subconscious. It has the great advantage of supplying a practical rule which can be applied in every instance, the only exception being when we use an intensifying screen which causes reversal of the image. This is an eventuality which we hope will become less and less frequent and which we shall discuss shortly after having roughly indicated what intensifying screens really are. Finally, on always viewing plates from their glass side there is no risk of scratching the gelatine and spoiling them by contact with the fingers.

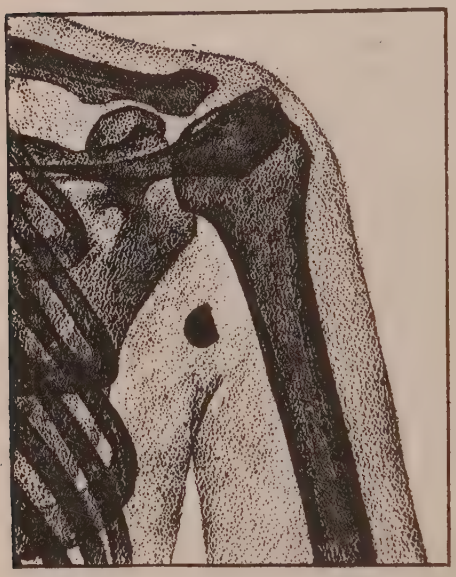


FIG. 28.—The same radiograph of the right shoulder seen from back. We now have a positive and the image is still presented as in the two foregoing figures. We observe the slightly deformed shrapnel bullet in the inner front part of the axilla. Its position on the radiograph enables us to *affirm* that it is *extra-thoracic* and lodged in the *soft parts*.

§ 9. **The Time of Exposure in Radiography. —Intensifying Screens.**—All other conditions being equal, the photographic action of luminous rays depends principally upon the two following factors: (1) the quality (wavelength) of the radiation; (2) the quantity of this radiation which is arrested by the sensitive layer. The respective variations of these two factors determine the length of time during which the radiation used should act; that is to say the *time of exposure* required to obtain a satisfactory plate. Exactly the same thing applies to radio-

graphy where a knowledge of the time of exposure is of capital importance. We have seen that the quality of the radiation is estimated in Benoist degrees and the quantity according to the number of milliampères—read with a milliampèremeter—which traverse the tube and to the time, calculated in seconds, during which it works. Let us assume that the sensitiveness of the emulsion is invariable and that the distance from the tube to the plate (for instance 60 centimeters) and the thickness of the part to be radiographed are constant. If, by using Benoist rays 5 and by passing 10 millis into our tube, we have secured a good radiograph of the shoulder in 25 seconds (or 250 milliampère-seconds), we shall always obtain a good image by always returning to the same conditions and by using the same time of exposure of 250 milliampère-seconds (which we can do by either exposing for .250 seconds with 1 milli or for 1 second with 250 millis, etc.).

In general it is best in radiography to use radiations of weak penetration exceeding only exceptionally No. 6 Benoist and the best results are obtained with rays 4 to 5. The images are much finer and richer in contrast, the details standing out clearly. In fact, according to its hardness or softness or, to be more exact, according to whether the wave-length be small or relatively great, an X-radiation will more or less easily traverse the interposed bodies of whatever nature they may be, and will produce more or less clearly contrasted shadows on the screen. The softer the radiation, and the more important the proportion of this radiation arrested by the same difference of atomic weight, the more differentiation there will consequently be on the images, whilst the harder it is the less striking will be the contrast. The images will be "grey." Another great advantage is that it is possible with soft rays to compensate by development the relatively considerable deviations in the time of exposure. With hard rays, on the contrary, the times of exposure must always be absolutely exact if we wish to obtain satisfactory plates, because even slight differences are sufficient to render the radiographs useless. Hence this great drawback more than balances the advantage derived from a shortening of the time of exposure which is possible with these rays.

For thick parts however, and if we have only weak installations at disposal, the length of exposure on using soft rays may become excessive and would constitute an obstacle to its use, were it not possible to remedy it by the use of intensifying screens.

Intensifying Screens.—These screens consist of sheets of cardboard on one side of which there is spread a homogeneous layer of some such substance as *tungstate of calcium* which becomes luminous under the action of X-rays, the radiations emitted being mostly violet or even ultra-violet radiations to which the photographic emulsion is as we know particularly sensitive. It is these radiations which intensify or strengthen the action unsufficient in itself of the X-radiation on the plate. With the screens which have been manufactured for some years past the time of exposure may be shortened considerably—in the proportion of 1 to 10. German industry had entirely monopolised this special branch of manufacture; but the war has shown that in this direction we were also able to do without it, and to produce equally good or even better articles. Messrs. Caplain-Saint-André and Roubertie, for instance, at present manufacture excellent intensifying screens. Care must always be taken to secure complete contact between the sensitive layer of the screen and the gelatine of the plate as the effect of the screen is only satisfactorily accomplished when the contact is absolute. For this purpose cassettes are used, the best type of which is at present represented by Drault's aluminium cassettes, which enable the pictures to be taken direct and without reversing the image (Chapter IV). As previously indicated (§ 8) this point is of the utmost importance. Most of the German screens were constructed in such a way that by using them the rays first traversed the glass of the plate, then the sensitive layer and finally the screen. Under these conditions the image obtained on the positive is presented, in relation to the radioscopic view of the same part of the body taken under normal conditions, like an image seen in a mirror. There is therefore a reversal of the image which may easily lead to an error as regards the part affected. Indeed such errors have been very frequent. This great drawback is not counterbalanced by any real advantage. The method which consists in

adjusting the plate as usual in relation to the source of rays produces (if a good cassette be used) images which are equally satisfactory from every point of view. *It should, therefore, always be employed in preference to the preceding method.*

Apparently however there is at present a tendency to abuse the use of intensifying screens. The desire to shorten the time of exposure is only justified when it is a matter of taking radiographs of mobile organs. Unless exceptionally powerful installations are used good radiographs in apnœa without a screen will be obtained only with great difficulty. Screens should, therefore, be used for most visceral radiographs, which require apnœa for complete immobility and perfect clearness.* But for bony structures there is no necessity to insist on this reduction in the time of exposure to the detriment of the quality of the image, and plates taken with a screen never give the fine detail shown in plates taken without a screen.

Moreover, after being used for a certain time the screens constantly show defects, spots, etc., which are reproduced on the plates and may be taken for foreign bodies. Such possibilities of error must never be neglected, and care must be taken when searching for very small foreign bodies to use plates only without the aid of an intensifying screen as far as possible.

§ 10. **Secondary Radiation.**—Amongst the important

* We distinguish :

(1) *Slow radiography* for which the time of exposure is counted in minutes. It is becoming more and more exceptional in view of the extension in the use of intensifying screens. The weakest instruments only may necessitate exposures of several minutes for thick parts if intensifying screens are not used.

(2) *Rapid radiography* for which the time of exposure is less than one minute, irrespective of the part to be radiographed. The use of the latter is the most general.

(3) *Very rapid radiography* for which time of exposure varies between one-tenth of a second and one second. It is now commonly used with high-power instruments, and is almost indispensable if it is required to examine certain mobile viscera (alimentary canal).

(4) *Instantaneous radiography* the time of exposure for which is less than one-tenth of a second. It can only be effected with certain exceptional apparatus. It is indispensable for obtaining sharp radiographs of the heart's outline.

advantages which we have pointed out in order to recommend the use of soft rays are images with sharp and contrasting outlines. Their absolute clearness depends, however, upon another important condition which we have so far not mentioned. In fact, it depends essentially upon the smallest possible quantity of secondary rays produced.

When an X-ray strikes an atom of a body, this atom

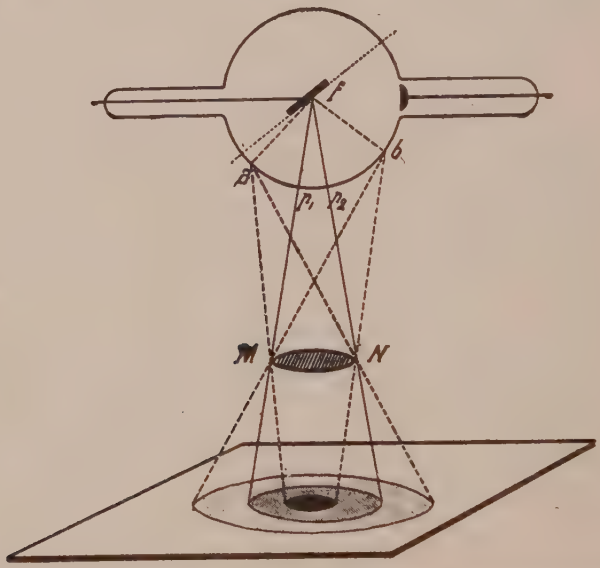


FIG. 29.—Supposing *MN* to be the object radiographed: We see that each of the secondary radiation focuses *a*, *b*, issuing from the walls of the tube will give a penumbra, and we can imagine the diminution in the clearness of the image which will result therefrom. A shield of a substance which is opaque to the rays, without which no tube should now be used, will to a great extent decrease the influence of the secondary radiation emanating from the walls of the tube, as is shown in the following figure.

emits in return another X-radiation which is called *secondary radiation* and the greater the penetration of the incidental radiation (called the *primary radiation*) by which it is produced, the more penetrating is this secondary radiation. This emission of secondary radiations discovered by the French physician Sagnac is of the greatest importance from various standpoints and especially in radiotherapy.

As regards radiography the secondary radiation has so far frequently been the cause of considerable annoyance, because each atom becomes in its turn a focus of rays. The clearness of the image would thus be considerably diminished as each of these sources would supply an image. We should thus obtain multiple images with penumbræ without the formation of a single shadow, and the clearness of the image might be affected to such an extent that it might be impossible to make use of it for radio-diagnostic purposes. If we do not take into consideration the secondary radiation of the air it will at once be apparent that in any X-ray operation we shall have to deal with two main sources of secondary radiation : that the first one will be formed by the wall of the tube and the second by the body to be radiographed.

It did not take long to discover means for eliminating the action of secondary rays emitted by the walls of the tube. Its deleterious influence on the clearness of the image is shown in Fig. 29. The diagram which follows shows that it is sufficient to enclose the pencil of rays emitted by the shield in a cylinder of such proportions that none of the injurious rays reach the screen or the plate (Fig. 30).

These cylinders are called *diaphragms*, and the difference in the clearness of plates taken with and without them is very apparent. Their use is absolutely necessary if it is desired to obtain radiographs which will show fine detail and especially satisfactory images of the osseous structures.

A simple diaphragmatic disc would not be quite satisfactory because it never eliminates more than a part of the secondary radiation ; but it enables us especially in the form of the iris diaphragm devised by Béclère not to be inconvenienced by the limitation and fixity of the area to be examined. This is a very considerable advantage especially in radioscopy which induces us to give it the preference over cylindrical diaphragms. Its influence on the clearness of images is extremely important ; this is especially noticeable when searching for projectiles. Very often when an examination is made with an open diaphragm the projectile is not visible ; it appears however when the diaphragm is closed and only a very small opening is left uncovered. We shall see later on that

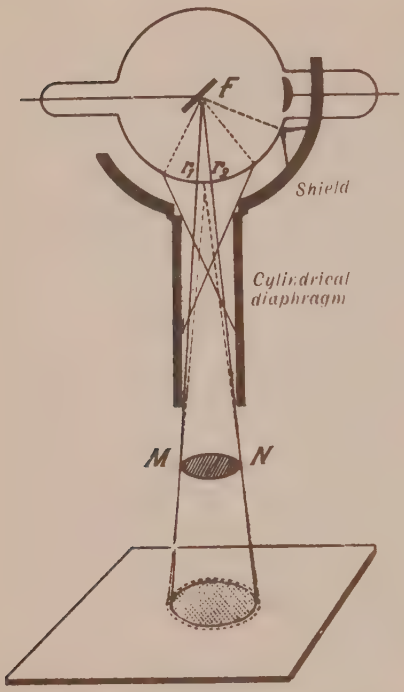


FIG. 30.—The shield itself arrests a considerable part of the secondary radiation. The cylinder diaphragm eliminates the influence of all the secondary rays so prejudicial to the clearness of the image, that escape through the opening of the shield as they are not included in the cone $r_1 Fr_2$. They are arrested on the walls of the tube if the cylinder is sufficiently long and narrow. The secondary rays generated in the zone $r_1 r_2$ of the tube's wall, and recorded in cone by $r_1 Fr_2$, will be all the less troublesome, due to the faint penumbra which they may produce, the longer and the narrower the diaphragm.

this is very important for the localisation of projectiles by radioscopic methods.

These devices do not enable us to eliminate the secondary radiation emanating from the body radiographed. It may be diminished by compression and especially by the use of soft rays which produce as already mentioned fewer secondary radiations than hard rays; so far there is no really practical means in existence to suppress it altogether, and its annoying influence especially in radioscop will still be constantly noticeable in examining the thick parts of the body (abdomen, pelvis) especially of stout patients.

§ 11. **Radioscopy or Radiography, and their Respective Indications.**—Whenever we require to make an examination we shall, therefore, have to employ these two methods which far from excluding each other form a mutual complement to one another. Radioscopy alone enables us to examine organs in motion and to study by palpation and mobilisation under the screen their normal and pathological relations under the most diverse angles of incidence. In the anatomical re-

search for and localisation of projectiles, it is especially adapted (owing to certain technique in mobilisation) to yield information of the utmost value.

If, however, we desire a permanent record, or wish to obtain the most complete details of bony structure, or if we wish to ascertain the presence of metal particles, we must resort to radiography which alone can supply all the minute details which the eye is unable to perceive on the screen. As our examination of the screen is made in the dark, that is to say under conditions to which the eye is not adapted, our *visual acuteness* is far inferior to what it is in full daylight, and does not increase in proportion with our adaptation. As demonstrated by Béclère this is the essential reason for the difference existing between the two kinds of images, radioscopic and radiographic. The following experiment will demonstrate this in a very convincing manner. A good radiograph of the thorax should be taken and examined in full daylight, and the existence of some minute particular detail noted. Thereupon it should be examined in a dark room by the light of a fluorescent screen placed against it. It will then be noticed that the details have disappeared, and that the analogy to a radioscopic image is almost complete. Should there be any difference it arises mainly from the crystalline structure, and granular condition of the platino-cyanide of barium which is less favourable to the production of clear images than the polished surface of the plate.

It is, therefore, essential in all difficult cases and in all such where it is of importance to obtain complete details, to take a radiograph after a radioscopic examination. Inversely we should not in similar cases be satisfied with a plate, which is an inert document, but should carry out a detailed radioscopic examination aided by our anatomical and physiological knowledge.

CHAPTER III

LAWS OF PROJECTION

PRIMARY IDEAS ON X-RAY INTERPRETATION

§ 12. **Projections and the Normal Ray.**—Being now able to practise radioscopy and radiography with apparatus and a technical knowledge calculated to give the best possible results from the standpoint of clearness and the detail of our images, and to permit of the elimination of secondary rays, let us now examine more closely the physical conditions contributing to their formation. These studies are in fact absolutely indispensable if radioscopic and radiographic shadows are to be correctly interpreted. By continuing to liken X-rays to luminous rays and their source to a luminous punctiform source we shall find at first that the shadows projected by any body interposed between that source and a fluores-

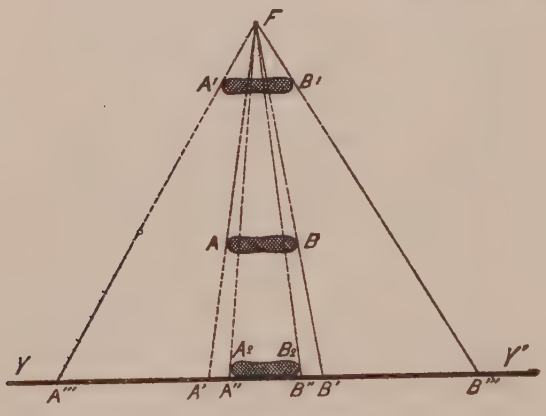


FIG. 31.—F being the luminous source, the opaque body AB projects its enlarged shadow at $A'B'$. The nearer it is to F in A_1B_1 the larger will its shadow $A'''\ B'''$ be. On the contrary if we place it at $A_2\ B_2$ on a level with the projection plane its shadow $A''\ D''$ will scarcely be increased.

cent screen or a photographic plate will strictly obey the laws of conical projections.

Thus as shown in the diagram of Fig. 31 the shadow thrown on a surface YY' by a body AB interposed between said surface and the point F, which is the source of radiation, will be all the larger the nearer the body AB is to the said source and the further from the plane of projection.

It will be all the nearer to the size of the object the further the latter is distant from the source and the nearer the plane of projection. This enlargement can be very easily calculated and a table prepared of its values. Similar tables have been published from which it may be seen that the enlargement for a source situated at a distance of more than two mètres is almost nil. In practice it may even be considered that the same obtains for a distance of 1 mètre 50. Radioscopy and radiography conducted at this distance (called teleradioscopy and teleradiography) are thus able to supply radiological images of natural size.

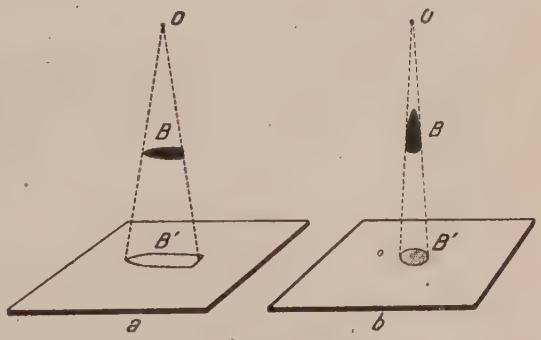


FIG. 32.—O being the luminous source, B a bullet interposed between it and the projection surface, it is possible, by a simple examination of the diagram, to see that according to the position of B its shadow B' will reproduce an enlarged form of the projectile, as shown in diagram a; or, on the contrary, it will reproduce a circumference (corresponding to the circumference of the base of the bullet) as shown in diagram b, all intermediary forms being also included.

But all radiological images are flat *projections upon one single plane*. The same object could therefore give entirely different shadows, according to the direction in which it is placed with regard to radiation.

Thus the shadow produced by a bullet B might appear, as shown in the diagrams of Fig. 32, under various forms.

Hence, a plate taken in one direction will not enable us to judge as to the real form of the projectile. Apart from their enlargement, X-ray images are also strangely distorted unless special precautions have been taken. A moment's reflection will suffice to show that it is the *incidence* of the radiation used in relation to the object examined and to the plane of projection which determines the degree of distortion (the distance of the tube from the plane of projection remaining invariable and the object being supposed to be stationary, in order to simplify the study of the variations). Amongst the three factors which are then to be determined: viz. position of the tube, position of the object (or subject) being examined, and position of the plate (or of the screen), that is to say the plane of projection:—it is most often the latter which has been considered as the most important in influencing the incidence of the ray and determining the other variable factors. If we adhere to this method of operation, and if we inquire which should be the position of the "plane of examination" (that is to say of the organ examined or part supposed to be placed on a plane), then we shall agree with Guilleminot that: "in order to see a region with minimum distortion it is necessary to place the plane of examination parallel to the plane of projection, and (unless there are special indications) select the frontal or sagittal plane, by placing the focus of the tube perpendicularly to the planes of examination and to the plane of projection passing through the centre of the region under consideration." The ray emitted by the focus of the tube, and which remains at right angles to the planes of examination and projection, has been briefly termed the *normal ray*. However, practical necessity soon made it necessary to extend and modify according to the authors who defined it the meaning of that term an exact knowledge and comprehension of which is of the utmost importance.

The most important point in War Radiology and especially in the localisation of projectiles is to maintain the same incidence in relation to the plane of projection and to be capable of re-finding it with certainty as the plane of examination is not necessarily parallel to the plane of projection. It is therefore merely necessary to choose as

a normal ray a well-determined ray which could always be found again at will and would always be the same.

But, nowadays, no tube is or must be used without being placed in a shield or protective box, impermeable to X-rays and which only allows them to pass through a determined opening generally circular. Let *BD* be this opening in the shield shown in diagram in Fig. 33. Thus only the cones of the rays *BFD* passing through that opening will be utilised. We can then place the tube in relation to its shield, in such a manner that the perpendicular of the focus *F* on the plane of the opening *BD* will at the same time pass through the centre of this opening, it being of course assumed that the focus is punctiform. It is *this ray* perpendicular to the plane of the diaphragm that we call the *normal ray*, and we say that the tube thus placed in relation to its shield is termed *centred*.

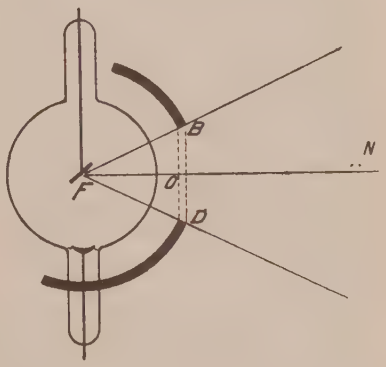


FIG. 33.—Assuming *F* to be the focus of the tube and *BD* the opening of the shield: The cone of the radiation used will be *BFD*. On so placing the tube in relation to the shield that the perpendicular of the focus on the plane *BD* of shield aperture passes through the centre *O* of this opening (that is to say coincides with the axis of the cone *BFD*) we shall then say that the tube is centred and the ray *FO* is termed the *normal ray*.

A simple examination of Fig. 36 will show us at once that if, other things being equal, we assume that the normal ray is perpendicular to the plane of projection or, what amounts to the same thing, if we presume that the plane of projection and the plane of the aperture in the shield (or the plane of the diaphragm) are parallel, then the radiological image of any object placed in the plane of projection will be more enlarged and distorted according as the object is removed further from the base of the normal ray and *vice versâ*.

We must therefore in practice approximate the region to be examined as near as possible to the plane of pro-

jection surface; that is to say we must apply it to the plate or screen, and adjust the zone of that region in which we are interested (and which we call the plane of examination) parallel to the plane of protection (plate or screen). Finally and especially we must operate only with a tube which is perfectly centred, so as always to know the direction of the ray which we have defined as the normal ray. It will have to be perpendicular to the plane of projection and consequently to the plane of examination; we shall arrange to allow it to pass through the most interesting point of this plane of examination, for instance the projectile, if it be a projectile that we are examining.*

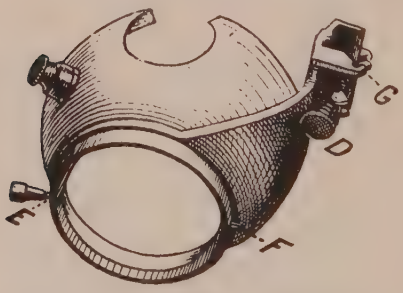


FIG. 34.—Shield of lead glass. The circular opening of the lower part defines the cone of the radiation used, and it is upon this aperture that the diaphragm is fixed.

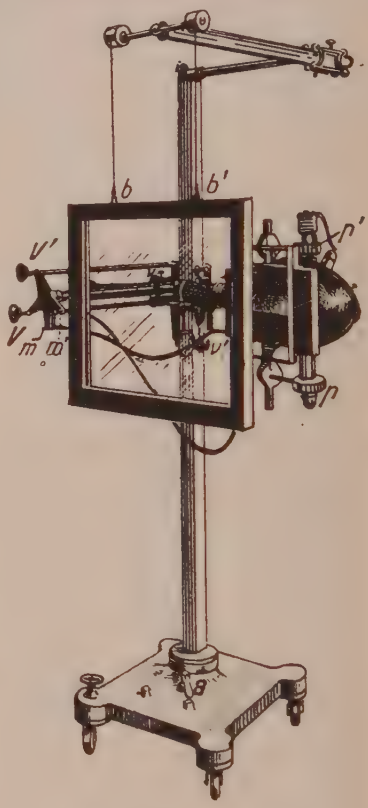


FIG. 35.—The tube placed on its carrier is centred in the interior of the shield which is provided with a diaphragm with movable shutters. The whole is fixed on a large tube stand designed by Dr. J. Belot (Gallot et Cie.).

* If the object under examination is too large to enable it to be treated as a point, we must make our arrangements in such a way as to adjust its longest diameter as symmetrically as possible in relation to the normal ray.

BOSTON MEDICAL
JUN 20 1918

A correct comprehension, perhaps a little difficult at first, of the normal ray and of the characteristics of the projections obtained is of the utmost importance in radiology; this is especially the case in the special sphere in which we are interested. Without such knowledge it is impossible to understand completely what is being done and to interpret the images observed. It is also useless to try to localise projectiles without an exactly centred tube.

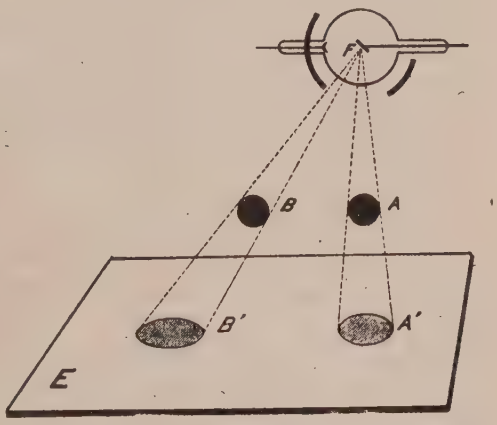


FIG. 36.—The projection (on the surface *E* of the screen or plate) of a shrapnel bullet *A* placed in the path of a normal ray will be the *enlarged but not distorted* shadow *A'*. If we place the shrapnel at *B*, outside the normal ray, its projection will be the enlarged and distorted shadow *B'*, and the distortion will increase in proportion as we move it away from the normal ray.

This centring, always very simply and rapidly effected with the instruments now supplied by our great French manufacturers, should therefore always be done on changing the tube. From this, as from many other points of view, everything supplied by foreign industry is much inferior to that obtainable in France. The others are only imitations and very often bad ones. Let us not forget that the first apparatus with tubes adapted to be correctly

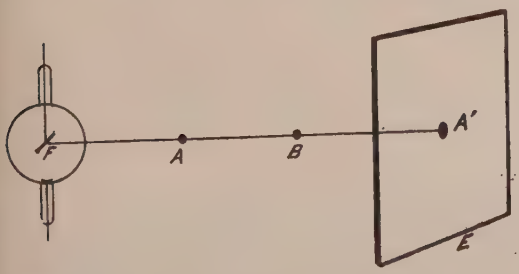


FIG. 37.—The shadows of the two opaque points *A* and *B* both situated in the path of the normal ray merge on the fluorescent screen *E*, into one shadow *A'*.

centred were produced in France owing especially to the researches made by Messrs. Béclère, Belot, Guilleminot, etc.

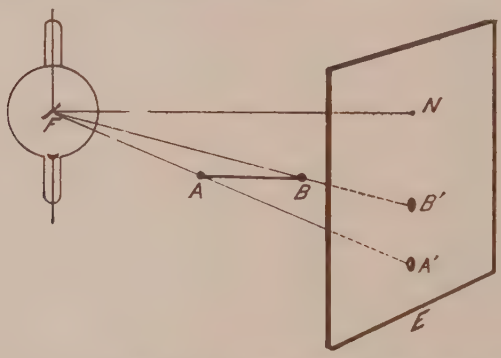


FIG. 38. – Let us displace the straight line AB parallel to the normal ray FN. The shadows of the opaque points A and B will be produced at A' and B', and the three points N, B, A will be on the same straight line.

This is how the centring is effected.

Suppose there are two opaque points A and B situated on the same axis. Let us make this axis coincide with the path of a normal ray. The shadows of A and B on

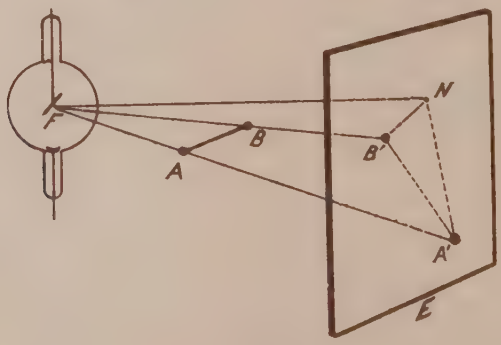


FIG. 39. If the straight line AB is moved in any direction in space no longer parallel to the normal ray FN, the opaque points A and B throw their shadows at A' and B' upon the fluorescent screen E, but A, B, and N are no longer on the same straight line.

the plane of projection will merge into a single shadow A (Fig. 37). Let us now displace the axis AB parallel but out of the axis of the normal ray.

The shadows A and B' of A and B will become separated, and the distance between them will increase in proportion

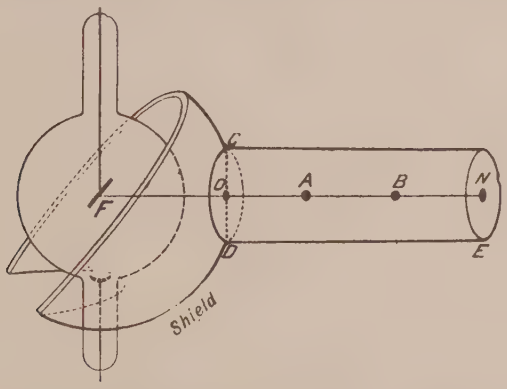


FIG. 40.—The tube is placed correctly into its shield, it is *centred*. The central ray of the focus F of the tube perpendicular to the plane of the aperture CD of the shield passes through the centre O of said aperture (normal ray). It thus passes through the axis of the tube indicating the incidence, and the two opaque points A and B of this axis project their shadows on to a single spot N on the small fluorescent screen E fixed at the free end of the tube.

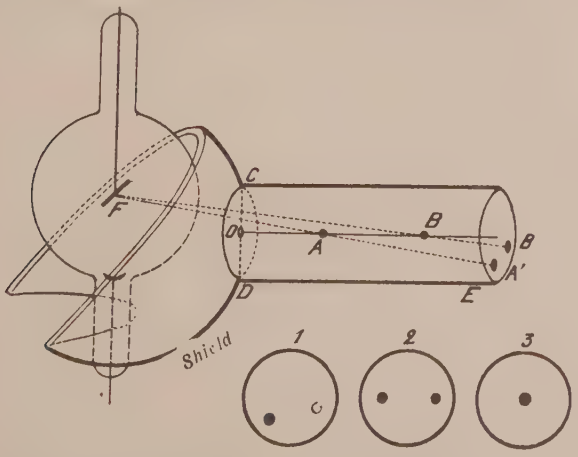


FIG. 41.—The tube is centred in the cupula. The opaque points A and B form their shadows at two different points A and B' of the fluorescent screen E, which is shown in front elevation at I. In order to centre the tube, it is first lowered vertically into the shield, until the screen shows the two shadows according to Fig. 2 finally it is moved horizontally until the two shadows coincide as seen in Fig. 3.

to the distance of the straight line AB from the normal ray FN, the three points N, A', B' remaining on the same straight line (Fig. 38). Let us now displace AB at random; the three points N, A', B' will no longer be situated in the same straight line (Fig. 39). This procedure will at once give us a means for constructing a simple and precise centring device. Let us fix two opaque points upon the axis of a metal tube T. Let us fit this tube on to the shield in such a way that its axis passes through the centre of the aperture in the shield, perpendicularly to the plane of said aperture. If the tube be well centred the normal ray will pass through the axis of our tube and, if we place a small fluorescent screen E (Fig. 40) at its free end, the opaque points will merge their shadows upon it into a single one at point N.

On the contrary, if the tube be not centred, the normal ray will not coincide with the axis of the tube, and the points A and B will project their shadows upon different points A' and B' of the screen (Fig. 41).

All that will be necessary then is to displace the tube in relation to its shield, first upwards and downwards and then from left to right, in order to obtain a coincidence of the shadows A' and B'.

When these shadows coincide and form a single image the tube will be centred.

In practice, each of the two opaque points is represented by the point of intersection of two metal wires. The centring device is a metal tube, in the interior of which there are two crossed metal wires, their intersection corresponding with the axis of the tube. One of the ends is mounted so as to fit accurately to the opening of the shield, and so that the axis of the tube can pass through the centre of this opening; the other end is free and carries a fluorescent screen on which the shadows of the crossed wires projected. By means of adjustments, provided for the purpose on the tube supports, the tube can be moved within the shield, at first in a vertical and then in a horizontal direction, until there appears on the screen only one well-defined shadow of the cross wires (Fig. 42). All these manipulations are easily effected by means of special screws on the tube-supports, the arrangement of which differs only in points of detail.

It follows from what has been said before that if we wish to interpret a radiograph correctly we must know where the end of the normal ray which indicates the zone of least distortion falls upon the plate. It will generally be found in the neighbourhood of the centre of the image

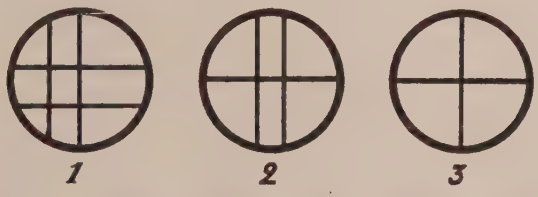


FIG. 42.—Diagrams 1, 2, and 3 show the aspects under which the crossed metal wires should appear successively on the small fluorescent screen, when a tube is centred by means of a centring device with crossed wires.

because we shall of course be careful to place the most interesting zone as exactly as possible near the centre of the plate.

A few examples will enable us to understand more fully the importance of the normal ray and the necessity for having a carefully centred tube if we wish to make any radiological examination, and especially if we have to localise a foreign body, because without it this operation would only lead the radiologist and surgeon into error.

Let us assume that the subject has a rifle bullet in his forearm which must be extracted. The surgeon must know where and how to make the necessary incision. The radiologist must therefore tell him exactly under what point of the skin the bullet is lodged. Let us pass the normal ray through the centre of the projectile P, and mark its virtual point of issue P' (Fig. 43) on the skin. To do this it will be sufficient to make a screen examination with a well-centred tube, to place the patient's arm in such a position in relation to the tube that the shadow of the bullet will appear on the screen in the centre of the luminous region determined by the diaphragm, and then to slide a metal rod opaque to the rays under the screen and in contact with the subject's skin until the shadow of its point coincides on the screen with the middle of the shadow of the projectile.

If leaving the point of the rod on the spot we cut off the current and remove the screen, then we can mark on

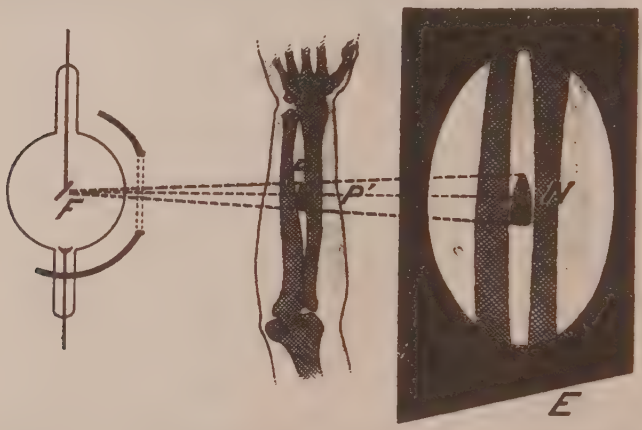


FIG. 43.—The tube is centred. The normal ray passes through the centre B of the projectile, and the end N of the normal ray is in the centre of the shadow of the projectile on the fluorescent screen E.

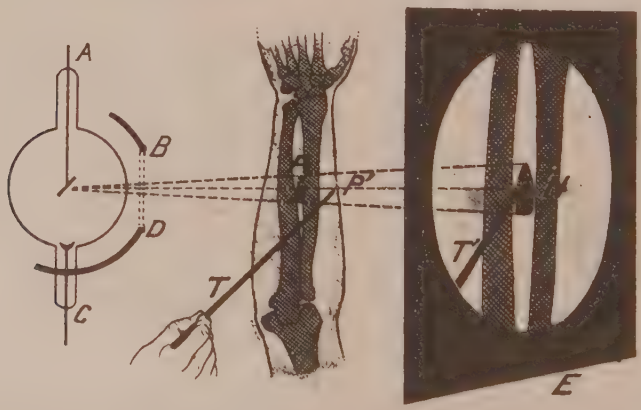


FIG. 44.—By means of a metal rod T opaque to the rays which we slide along the skin under the screen until the shadow of its point coincides on the screen with the centre N of the shadow of the projectile we determine the point P' of issue of the normal rays (passing through the centre of the projectile) on the skin of the forearm. The projectile is situated under that point.

the skin with a dermographic pencil (or by any other means) *and thus indicate definitely the point of issue of the normal ray* (Fig. 44).

This very simple manœuvre is of the utmost importance in radio-diagnosis of projectiles and we shall meet with it continually. It is an essential part of all radioscopic localisation. In the example under consideration it will indicate to the surgeon his line of incision, because he

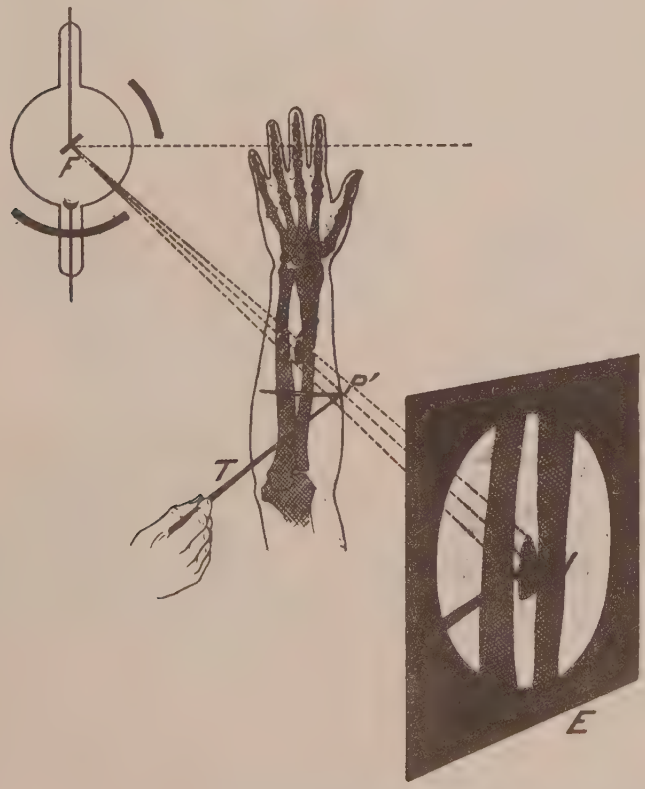


FIG. 45.—The tube is no longer centred. We have used an oblique ray *FN* and determined its virtual point of issue *P'* on the skin of the forearm. The projectile will not be situated under this point and the deviation may be sufficiently large to prevent an incision, made at the level with that point, from reaching the projectile.

knows that the projectile is lodged vertically in the tissues under the point marked.

Let us suppose, however, that the tube is wrongly centred and that the rays follow an oblique route shown

in the diagram (Fig. 45). In that case the point marked on the skin will be the emerging point of any one of these oblique rays, and will cause the surgeon to make a mistake because he will be guided by it and will be searching in vain for the projectile in the tissues underneath that point.

In this connection we must note how the least difference in the determination of the plane of examination will give rise to a deviation in the emerging point of the normal ray on the skin.

Fig. 46 shows diagrammatically with reference to a

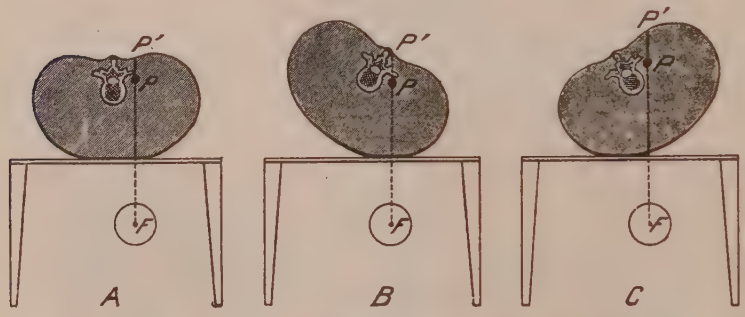
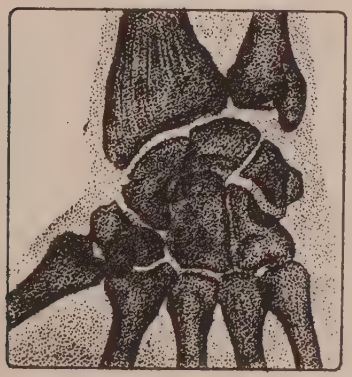


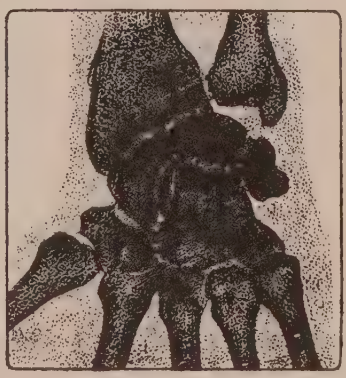
FIG. 46.—Let us assume that *P* is a shrapnel bullet close to the spine situated slightly in front of a transverse process. The patient is placed on his abdomen on an X-ray couch in a position suitable for extraction. According to whether he is situated exactly in ventral decubitus—Diagram *A*—or slightly inclined to the side—Diagrams *B* and *C*—the point of issue on the skin *P'* of the normal ray passing through the projectile will be subject to considerable deviations which may cause it to pass over the median line or even to the other side of that line.

projectile close to the spine the utmost importance of this orientation in localising foreign bodies.

We have now to examine a radiograph of the wrist in order to determine the state of the radio-carpal articulations and the existence of any bony anchylosis. We have directed the path of the normal ray upon the joint (this is called in X-ray language *centring* the joint). The plate shows that the articular spaces are clear and intact, there is no anchylosis (Fig. 47). But here is another plate (Fig. 48) not correctly centred; the path of the normal ray corresponds more or less to the middle of the forearm.

The articular spaces have disappeared and are covered with distorted projections of the bones of the carpus and of the forearm. If we have sufficient experience we shall not express any opinion with regard to this plate which is of no value to us and we shall take another under proper conditions; that is to say with a perfectly centred tube, being careful to centre the proper region. But we may easily err in the diagnosis and pronounce the existence of anchylosis if our X-ray experience is not sufficient or if a too hasty and superficial examination of the plate has not enabled us to judge correctly of the superimposition of the shadows of the inferior extremity of the radius and of the bones of the first row of the carpal bones which





FIGS. 47 and 48.

immediately shows the distortion of the image and the absence of correct centring.

These examples could be multiplied *ad infinitum*. They demonstrate the absolute necessity of using only perfectly centred tubes, and of verifying the centring from time to time. Henceforth when we speak of any X-ray operation it will be understood implicitly that this condition has been fulfilled.

There may be however some instances where it is advantageous to use oblique rays. This was very forcibly demonstrated by M. Béclère, when making an X-ray diagnosis of interlobar sclerosis.

Fig. 49 shows us the layer of sclerosis, and makes it

clear that the normal ray and all the rays which meet it almost normally traverse it very easily in view of the slight thickness of the indurated tissue to be traversed.

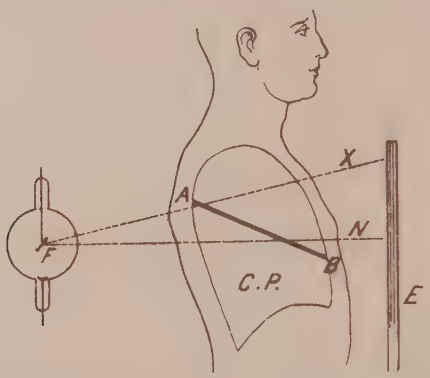


FIG. 49.—Let us assume that *AB* is an interlobar patch of consolidation situated in the pulmonary region *CP* and irradiated from the back towards the front. The rays *FN*, *FX*, etc., which are emitted from the focus *F* of the tube and illuminate the fluorescent screen *E*, have only to traverse the thickness of that thin layer of consolidation (quite insignificant even if taken slightly obliquely and consequently unable to stop them) and so no shadow will be produced. This condition therefore will pass unperceived during the examination.

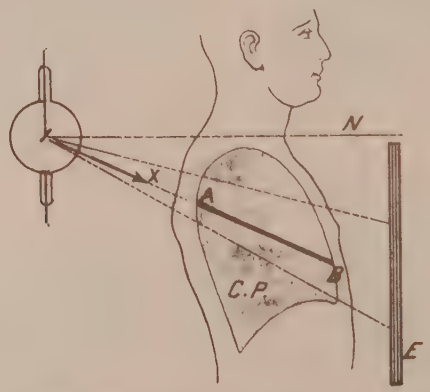


FIG. 50.—If on the contrary we place the tube so as to use oblique rays in the same direction as the layer *AB*, it will be seen that rays such as *FX* will have to traverse the layer *AB* along its whole length. They will, therefore, be stopped to a great extent and the shadow of the layer of consolidation *AB* will appear on the fluorescent screen *E*.

It will, therefore, not produce any shadow on the screen and will evade our radioscopic examination. Let us, however, arrange the tube (Fig. 50) so as to utilise oblique rays. These rays, the obliquity of which will be the same as that of the layer of consolidation in their path, will have to traverse the whole length of that layer (that is to say a considerable thickness of indurated tissue). They will, therefore, be stopped and we shall see on the screen the shadow of the indurated pleural band. These considerations apply especially to thin pieces of metal which, seen from the front, are very transparent and very often escape detection, but seen from the edge they appear immediately. It is, therefore, always necessary to move the tube during a radioscopic examination in all directions in order to find the projectile (Chapter V).

We have so far had under consideration X-ray images as conical projections only. A knowledge of the normal ray enables us to obtain on the screen *orthogonal projections*. By means of various pieces of apparatus, such as those of the Béclère type, or of the tube holders constructed by Drault and by Gaiffe (model of Dr. J. Belot), we are able to move at will the normal ray in space. It is thus possible to make this ray follow tangentially the whole circumference of an organ such as the heart. By marking successively on the screen each of the points of that circumference we shall be able to determine the orthogonal projection of that organ because we shall have operated with parallel rays. This process is called orthodiagraphy (Fig. 51).

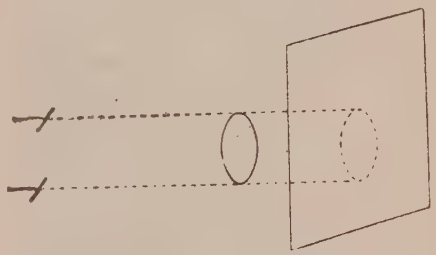


FIG. 51. Diagram showing how an orthogonal projection is obtained by displacing the normal ray parallel to itself.

We shall thus be able to obtain the actual measurements of objects and organs and especially to determine easily the characteristics of the embedded projectiles if we can ascertain their principal diameter. If for instance a bullet

can be perceived radioscopically along its main axis, we shall only have to pass the normal ray at first through its base and then through its point and mark each of these points on the screen in order to obtain its length. It is however sufficient to examine Fig. 32 in order to understand that the orthodiagram of an organ varies essentially with the aspect of that organ in space. Therefore before taking into consideration the outline obtained as indicating the true size of the heart it will be necessary, in order to avoid a too frequent error, to make certain that the large axis of that organ is parallel to the plane of projection.

We have seen already that teleradioscopy and teleradiography enabled us also to obtain practically orthogonal images which are however subject to the same restrictions.

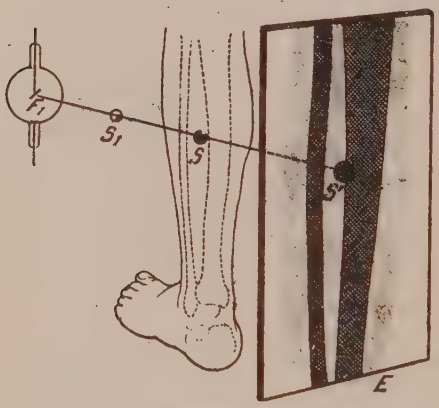


FIG. 52.—Whatever the position S, S_1, etc., of a projectile on the course of a normal ray projected from the focus of the tube F, the position of the shadow S' of that projectile will not be modified on the screen E, or on a plate. Only the size of the shadow will vary (according to laws which we have already explained). The image obtained in this position cannot, therefore, show us the exact site of the projectile along the normal ray.

As regards war practice, in which we are almost entirely taken up with measuring projectiles, our orthodiagraphy will be limited to marking on the screen the normal projection of the ends of the projectile in one or perhaps two diameters, a method for the first development of which we are indebted to Destot.

§ 13. **Interpretation of X-ray Images.**—Whilst keeping in mind the preceding considerations we shall now be able to undertake the practical study of X-ray images. Let us consider any foreign body, say a shrapnel bullet retained in a part of the body, say the leg. Let us make an antero-posterior examination, that is to say with the posterior surface of the leg nearest the screen (or plate).

The diagram in Fig. 52 shows at once that the position of the shadow of the bullet on the plate will be exactly the same, whatever the position of the projectile as to the normal ray, in other words *whatever its depth*. It may even be situated outside the limb—above or below—and the image will not be modified except as regards the size of the shadow. A plate taken in one direction does not therefore enable us to form an opinion as to the real position of the foreign body, which, if the tube has been well centred and if the projectile is lying in the course of the normal ray, will be found situated at some point on that normal ray, between the focus of the tube and the plate (or screen). Let us now place the leg sideways, its external surface on the plate, viz. 90° from the preceding position, and let us make another examination either with the screen or with a plate.

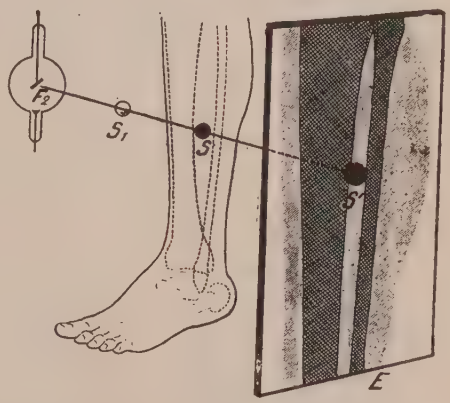


FIG. 53.—If the examination is undertaken in another position, at 90° from the former one, the same considerations will apply to the image obtained. But we have now obtained *two* distinct images, and on each of these we know the point of entry or exit of the normal ray which corresponds to the shadow of the projectile, which will therefore be situated at the point of intersection of the two rays.

The above considerations may still be applied (Fig. 53). The foreign body is situated in the path of the normal ray which is perpendicular to the preceding one. If we consider a section of the limb according to the plane passing through the projectile and determined by the two normal rays, it is evident that the projectile is situated at their intersection (Fig. 54). The two plates at right angles will enable us to imagine these two rays in space, and to form an approximate opinion of the position of their point of intersection from the standpoint of topographical ana-

tomy. We shall see later on how these data can be utilised for the purpose of obtaining a more exact localisation of the site of foreign bodies.

We thus see the absolute necessity of having images in two directions at right angles to each other, if we wish to be able to obtain an idea of the real respective position in space of the parts whose shadows have been projected on the plates (or screen), because a single image in a single plane does not signify anything, either as regards the form or situation of the projectile radiographed. This shows clearly how much to blame was the inexperience of those who at the beginning of the war were carried away by first impressions and thought that they knew sufficiently accurately the position of a projectile of which they saw the shadow on a plate as to be able to extract it at once surgically. Their failures soon showed them their mistake.

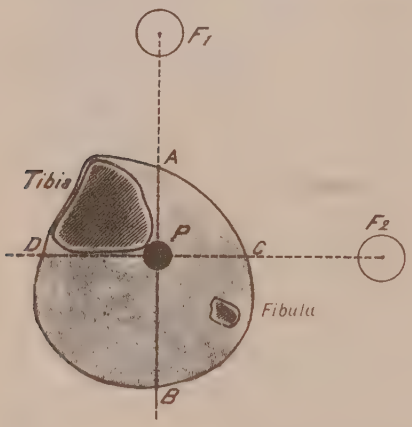


FIG. 54.—Let us imagine a section of the leg according to the plane determined by the two positions of the normal ray shown in the two preceding figures. Let us suppose it is the superior segment of the section. The projectile is situated at the intersection of the two rays. If we materialise these rays by marking on the skin their points of entry and exit, *A*, *B*, *C*, *D*, we see that we can find out almost exactly the position of the projectile in the tissues, that is to say we can localise the projectile.

The X-ray examination of fractures also shows us very clearly the necessity for two plates—or two radioscopic images—at right angles if we wish to find out the displacement, reduction or union, etc., without committing grave errors. The diagram (see Fig. 55) is sufficiently explanatory. Let us also remember that radiography alone enables us, as explained in § 12, to find out the exact condition of bony injuries.

Very often it is of great advantage to be able to examine a region not only in two planes at right angles to each other, but in various other planes. This is where radioscopy comes into its own, and offers an indisputable superiority. In fact under the screen the limb may be rotated and made to assume any position required. We could thus make sure for instance, in the case of a projectile the shadow of which seems to lie within the tibia on the plate, that it is not actually without the bone, and we can thus affirm that this projectile is intra-osseous. The same degree of certainty could not be obtained, even if we ascertained that its shadow still remained intra-osseous, on two plates taken at right angles to each other, because this appearance could have

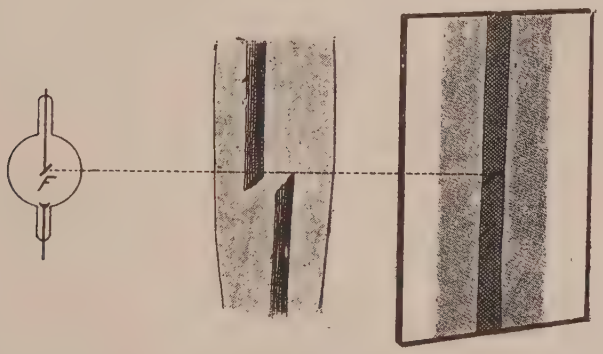


FIG. 55.—At the angle shown in this figure, we obtain an image which might make us believe, were we satisfied with it: (1) that there is union between the fragments, and that the fracture is uniting; and (2) that the position after reduction is quite straight. This shows, however, how erroneous these conclusions would be.

been due, in the case of a projectile in the soft parts, to the alteration caused by taking the two plates in a different position, owing to movement in the soft parts.

This does not mean to state that sometimes an image on a single plane may not allow an experienced radiologist to make deductions as to the real site of a projectile. The aspect of a bony injury, for instance the presence of an area of decalcification, would often justify the conclusion that the projectile was intra-osseous, but even then—we shall discuss this later—the diagnosis would have to be made carefully because of the numerous likely causes of error.

Moreover, in order to be able to estimate bony injuries correctly, it is necessary to have an absolute knowledge of the normal forms and aspects. But the projection of the same portion of the body may evidently assume the most different forms, varying with the different positions of the tube or of the plane of examination or projection. It is, therefore, usual to consider for each region one or two typical positions generally taken if possible one in a frontal plane and the other one in a sagittal plane. Most of the X-ray atlases reproduce them and are very useful for purposes of comparison to those who have not got these typical appearances sufficiently in mind or have not at their disposal a complete collection of normal plates. Amongst others the reader could refer to Hauchamp's atlas. A more or less trained radiologist can recognise at once by examining a plate under what circumstances it has been taken. For instance, he will be able to distinguish immediately whether he has before him an image taken from the anterior surface or the posterior surface.

Finally, it is necessary to know not only the normal X-ray anatomy of the skeleton but also all the variations and abnormalities of form and of number (supernumerary bones, etc.), in order to avoid grave mistakes which are being committed every day. It should never be forgotten that in case there is the least doubt as to the appearance observed, a plate should be taken of the corresponding part of the body on the other side for purposes of comparison. Great experience is also necessary in order to be able to distinguish the differences in the intensity of the shadows, so as not to mistake for instance a sequestrum for a projectile. We shall deal with this subject later on (Chapter V). As regards pathological images, experience only will enable one to interpret them correctly and to deduce thereby useful information for the surgeon. We cannot of course enter into explanations of this subject here, even in a general way, as the domain of clinical medico-surgical radiology has been enormously developed and is increasing day by day. We can only advise those who are interested in the matter to study special books and to read the *Journal de Radiologie*.

But the few indications given here will suffice to give some idea as to the difficulties and importance of a correct

and complete interpretation of X-ray images, and of the necessity of acquiring a perfect mastery of the technical knowledge required, in order to obtain all the information which radiology is now able to supply in any given case as regards the question of the search for and localisation of projectiles. We are still very far in many cases from deriving the fullest benefit possible on account of our inability to interpret correctly what we see.

CHAPTER IV

INDISPENSABLE X-RAY APPARATUS. MEANS OF PROTECTION

§ 14. **Radiographic Apparatus.**—To start with we must distinguish between the apparatus proper for producing X-rays, which includes on the one hand the means for producing the high-tension current necessary for working the tube, and also the tube itself, and on the other hand subsidiary apparatus for purposes of conducting the examination, such as tables, screens, etc. We shall not dwell very long on the part of the apparatus for producing the rays, because as regards this we may say that all or almost all installations are suitable for finding, marking and extracting the projectiles radio-surgically. In fact, any installation enabling us to pass through the tube from one to two milliampères with a sufficiently hard tube (that is to say with a spark gap which is equivalent to about a dozen centimeters at the most) will supply us, if we use it judiciously and especially if we possess well-seasoned stable tubes, all the intensity required for our radioscopic examination (provided always that the installation is a good one).

A. Installations.—Every type of installation which is able to fulfil these conditions and to produce regular working may be considered good. Such is sufficient for our radioscopic requirements and can supply very good plates in experienced hands, the only difference being an increase in time of exposure. We shall therefore not describe specifically the numerous models of weak or strong installations supplied by the manufacturers. They may be all narrowed down to practically two well-known types, either the induction coil (Fig. 56) or the rotary transformer (Fig. 57), the advantages and disadvantages of which we shall not discuss. Special treatises and the constructors' catalogues give the reader all the necessary information on these points by giving him a description of the essential

constituent parts of these instruments (interrupters, coils, etc.) and will explain to him their working should he not know it. It is hardly necessary to add that the apparatus used on the X-ray cars of the Health Service are perfectly adapted for all requirements within the limits of our subject.

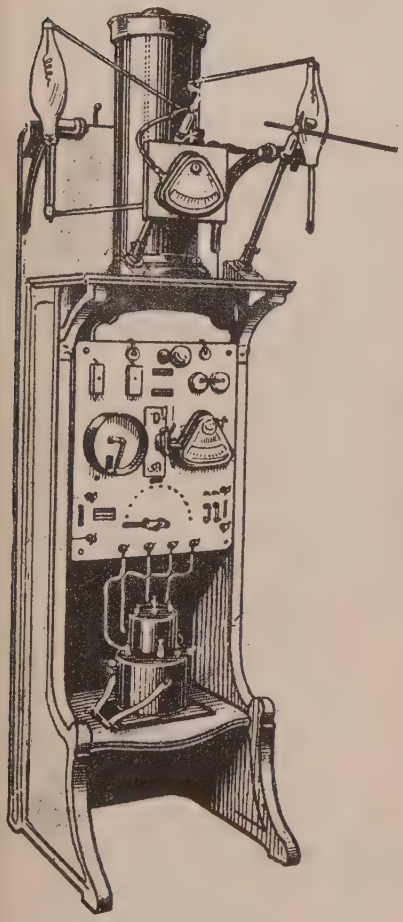


FIG. 56.—Set of apparatus produced by Gaiffe (Gallot & Co.). The high-tension current is supplied by the coil seen at the top of the shelf. On each side of the coil can be seen the valves the purpose of which is to stop inverse current (Chapter I. § 2).

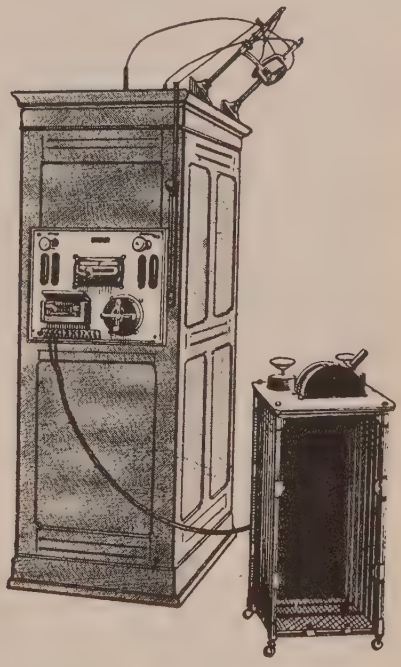


FIG. 57.—Small transformer by Drault (Chapter I. § 2). The two Figs. 56 and 57 were not made to the same scale and do not therefore admit of comparison in size.

We shall only mention that the constant increase in X-ray examinations has caused X-ray laboratories to be

installed as additions to almost every surgical service of any importance, and the custom of removing projectiles under the screen has made it desirable to create apparatus which, whilst answering all the requirements for complete examination and marking, are easily portable for the purpose of being used in operating theatres.

So-called " Portable " installations, the essential purpose of which was the obtaining of radiographs at home or at country places away from a fixed installation, have been in existence in rather large numbers, but as they almost all of them were based on utilising accumulators as the source of current, the intensity supplied by them was hardly sufficient and they hardly answered the purpose for which they were needed. One of us has therefore had constructed by MM. Gallot-Gaiffe an apparatus which answers all the latest requirements.

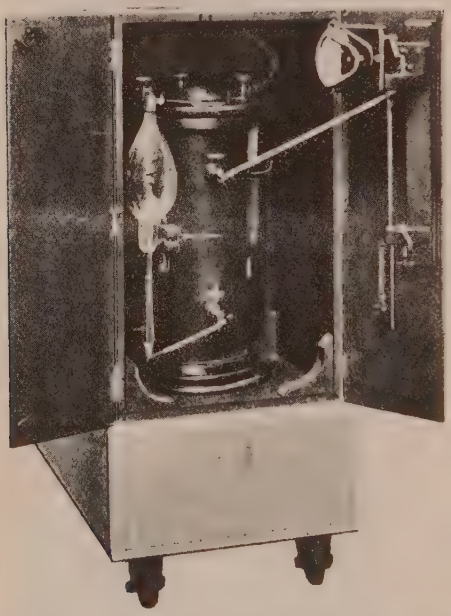


FIG. 58.—Radio-surgical cupboard by Dr. Ledoux-Lebard seen from the front which is open and shows the coil, the valve tube, the spintermeter and the milliampèremeter.

Portable Radio-surgical Apparatus.—The object desired was to combine absolutely *all* necessary radiological material, with the exception only of the operating table in the smallest possible compass, in the shape of a piece of furniture which would contain it completely and could be easily moved from one room to another and be adapted to all the usual lighting mains.

Its total height, including the castors, is 1·02 m., its width is 0·62 m., its depth 0·41 m. It is made of white varnished wood and the strong double castors which

support it are covered with indiarubber. The whole apparatus is thus fitted together and is dust-proof and also proof against accidents and interference, with a single safety key which locks the different doors. The whole piece of furniture is divided into two superimposed parts, each part forming a cupboard.

The lower part contains various accessories: such as the fluorescent screen and localising apparatus, opaque gloves, spectacles, bonnet, etc.; in short all that the radiologist requires for finding, localising and extracting projectiles by means of a screen examination.

Fig. 58 shows this arrangement from the front. We can see the valve, the coil, the spintermeter and the milliampèremeter. Fig. 60 shows the back part of the cupboard with the controls and interrupter. We may add that this piece of apparatus which has been constructed to work on an alternating current of fifty periods at a voltage of 110 can also be made to work with continuous current

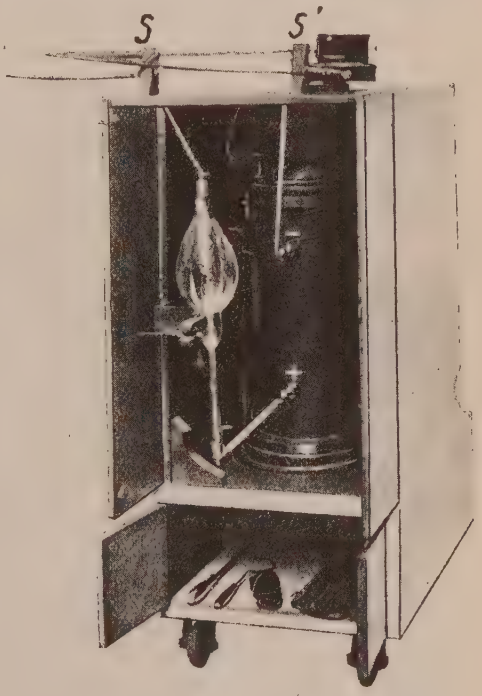


FIG. 59.—In order to use the apparatus all that is required is to pull out the holder which carries the valve and to lift out the spintermeter and milliampèremeter. All that remains now is to connect the tube to the extremities *S* and *S'* of the spintermeter. The small lower compartment containing the various accessories is shown closed in Fig. 58 and open in Fig. 59 in which we can see the various accessories (such as gloves, spectacles, pointers, ink marker).

There only remains the addition of the X-ray couch—which can be used as an operating table—of one of the types to be described later on, in order to have a complete and easily movable unit containing all necessary accessories. It is very easy to start the apparatus working, all that is required being to lift out the spintermeter

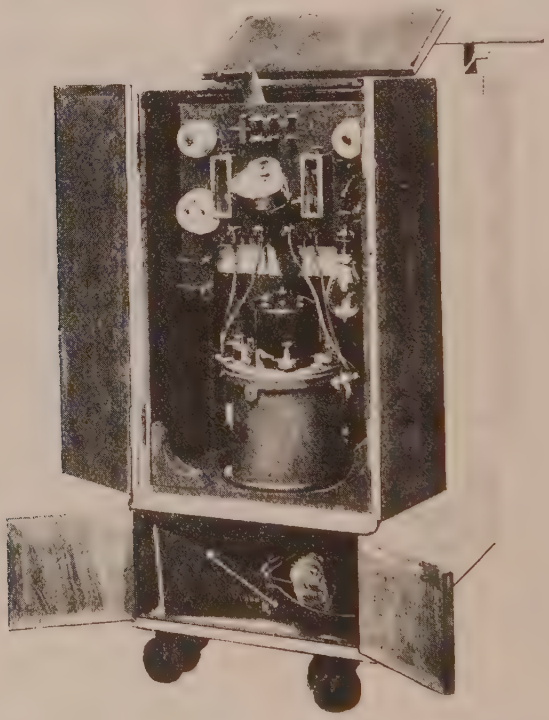


FIG. 60.—Radio-surgical apparatus by Dr. Ledoux-Lebard seen from the back which is open and showing the interrupter and controls. The small lower compartment is open and shows the cryptoscope of Dr. Dessane.

which we see hanging along the panel in Fig. 58 and to bring the valve tube forward. After this the tube should be joined to the two ends of the spintermeter (Fig. 59).

With this appliance and the X-ray car it is easy to be able to undertake a complete examination anywhere, and to proceed with the extraction of projectiles by means

of the screen in any operating room. (It is also possible to place a set of apparatus of the usual type on rollers and to render it thus portable to a certain extent.)

B. Tubes.—Any tube will be suitable which can carry for some time a current of 1 to 2 milliampères with a spark gap of 12 centimeters. For low intensities up to 1 milliampère no tube is better suited as regards strength

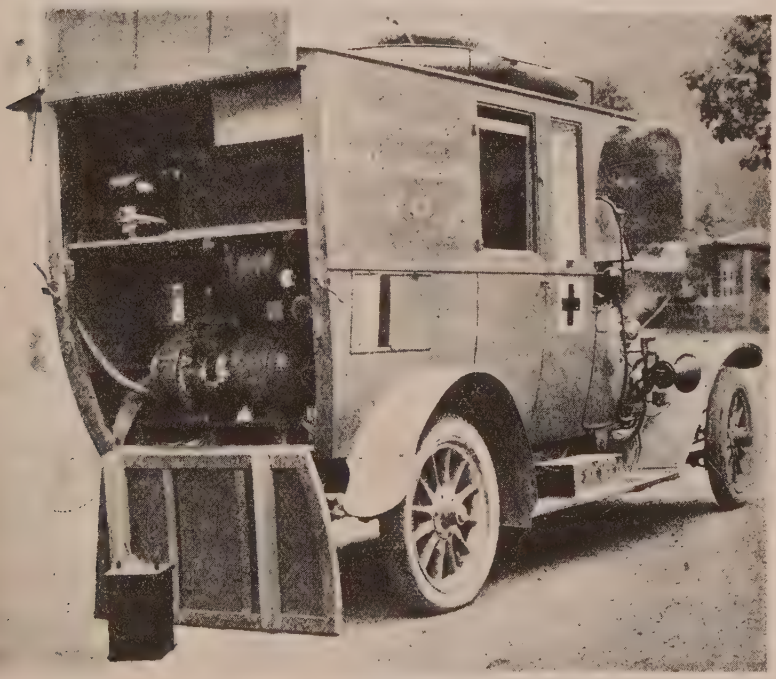


FIG. 61.—X-ray car constructed by the firm Gallot, a type used by the armies and at the bases.

and capacity than the Chabaud tube. We wish to point out that it is a mistake to use large tubes on weak installations and to work say a large Pilon OM, on a coil the maximum capacity of which is 1 milliampère, because these tubes will tend constantly and inevitably to harden very quickly and will not work satisfactorily.

It is advisable of course to choose tubes provided with regulators, preferably with Osmo-regulators.

An indiarubber bag filled with gas can be used easily

to take the place of the usual jet when there is no available gas supply in the vicinity. It would be useful to have, for the localisation and extraction of projectiles, tubes with a double anticathode. Unfortunately, their construction offers from a technical standpoint very great difficulties when it is desired to obtain tubes able to support a sufficient strength of current (1 to 2 milliampères per anticathode) for long periods, and the present conditions of manufacture do not lend themselves easily to new attempts in that direction. However, the firm Pilon has been able

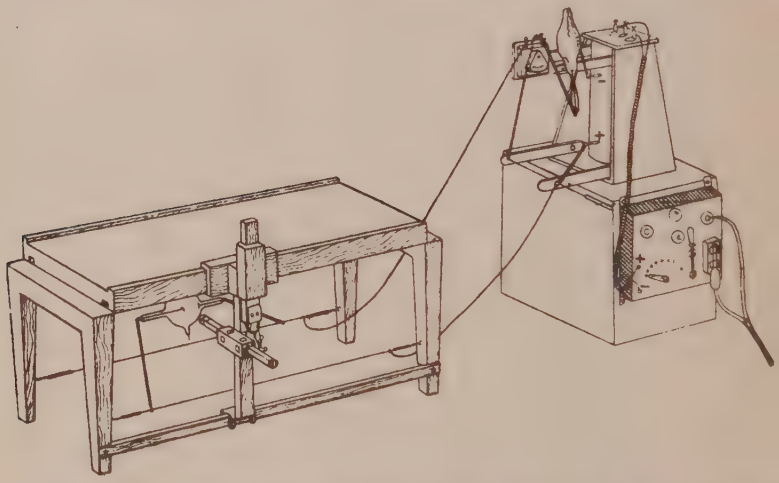


FIG. 62.—X-ray table belonging to a motor car fitted up with Delapchier apparatus and diagram showing the arrangement (military X-ray apparatus, Gallot & Co.).

to construct a remarkable tube with a double water-cooled anticathode and we believe that we shall see in future a more frequent application of these tubes, probably in the form of Coolidge tubes, in view of the exceptional facilities they afford under numerous circumstances.*

C. X-ray Shields and Tube Holders.—It is of course evident that a tube must never be used without being fitted into a shield and placed in a holder.

* Particulars relating to these tubes from the practical and theoretical standpoint will be found in the following article: R. Ledoux-Lebard et A. Dauvillier, "Les ampoules à double anticathode" (*Journal de Radiologie*, 1916).

It is thus possible to obtain a correct centring of the tube and to limit at the same time the pencil of X-rays in the required direction, and to obtain a protection against the greater part of the lateral rays, which are of no use to the examination and which are a source of danger to the operator.

We must point out that the centring of the tubes must be effected very carefully whenever the tube is changed.

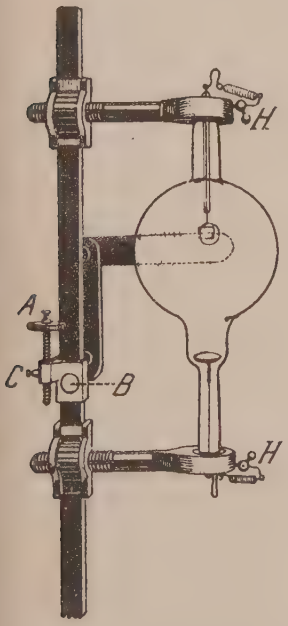


FIG. 63.—A tube fitted into its holder as seen from the front.

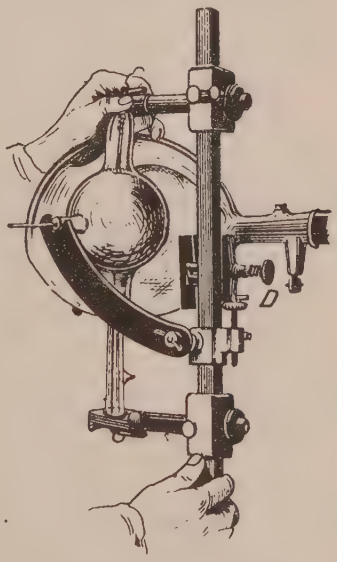


FIG. 64.—A tube fitted in its holder and placed in a shield in which it should be centred (from the back).

It should also be possible to fit on the shield a movable diaphragm—a diaphragm worked from a distance by means of a flexible connection

§ 15. **Apparatus for conducting the Examination.**—This includes first of all the arrangements for moving the tube and for examining the patient, the proper X-ray material and especially the cryptoscopes and X-ray accessories (intensifying screens and their cassettes), and also all the usual accessories of a character not strictly radiological.

We are not describing here special appliances for localisation, because they will be described later on.

Examination standing up and lying down. Tube Stand. X-ray Table.—Up to a few years ago X-ray examinations were generally made in a vertical position by means of a tube stand enabling the position to be changed in every direction, behind a screen of thin wood or of other material, against which the subject to be examined was placed. A movable fluorescent screen was placed near the observer and, if desired, could be replaced by a carrier capable of holding a plate with or without an intensifying screen. The Béclère and Guilleminot stands, impudently imitated and copied by Germans and Austrians, were the prototypes of the appliances now generally used and of which they served as a direct model.

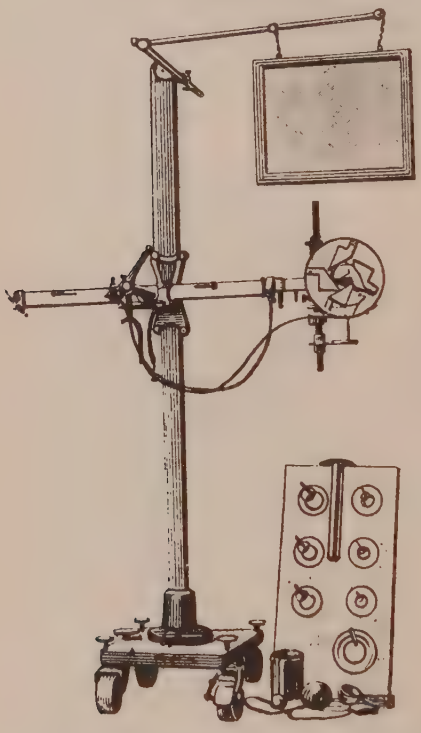


Fig. 65.—Large tube stand by Drault and Raulot-Lapointe which enables the tube to be moved in every direction.

The large stand by Drault and the large one by Bellot-Gaiffe are at present the most perfect models of these stands (Figs. 35, 65). These tube stands or others of a simpler design are also used to take radiographs by placing the subject on the table and by fixing him in the required position for the part to be examined, as shown in Fig. 66.

Wounded soldiers were at the beginning of the war often examined in a vertical position. But as they have to be operated on in a recumbent position and as the changing from one position to another may bring about important

changes in the relative position of the organs and consequently also of the projectiles, it was soon found neces-

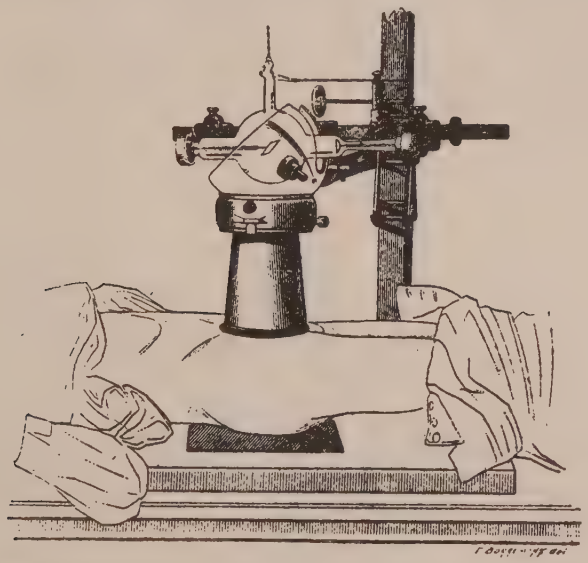


FIG. 66.—Fixed on a tube stand, the tube is centred in its shield to which is fitted a compressor tube. The patient is placed on the table and a radiograph is about to be taken of his right thigh in an antero-posterior direction.

sary to carry out the marking in the operation position (see Chapter VIII). Thus a start was made with screen examinations in a recumbent position. To that effect the existing stands were used, as shown in Fig. 67, under a table. But this expedient, useful in case of necessity, is

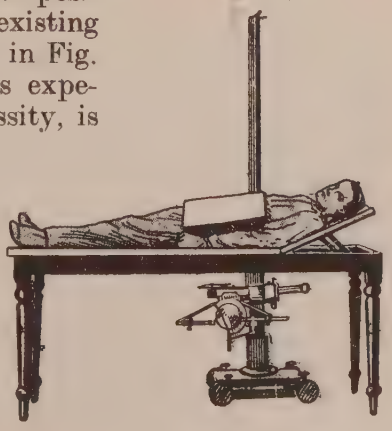


FIG. 67.—A tube stand provided with a tube centred in the shield is placed under a table, so as to be able to undertake a screen examination (and eventually to take a plate in an upward direction) of the patient placed on that table. But this is only a make-shift appliance.

rather uncomfortable if it is to be often repeated. Moreover, the foot of the tube carrier is rather in the way when it is necessary to operate by means of a screen and completely hinders the movements of the surgeon's assistant.

We therefore strongly advise the use of X-ray tables specially provided with a carriage enabling the tube to be moved in every direction under the table and parallel with

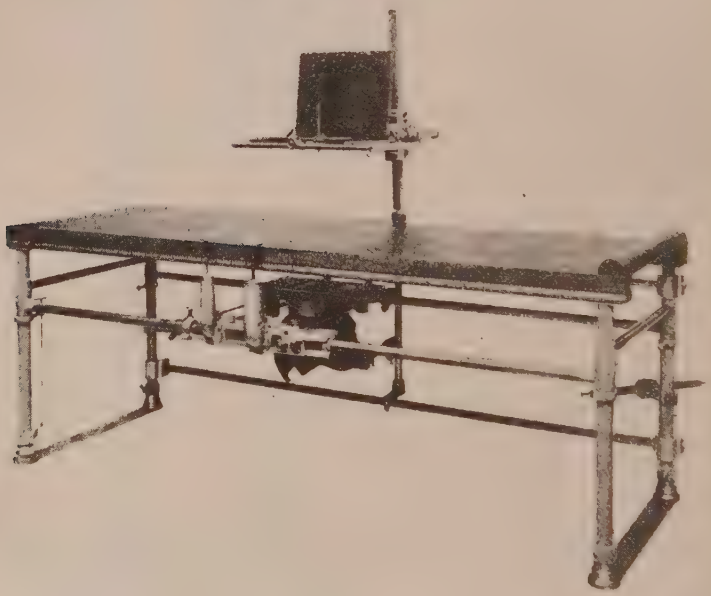


FIG. 68.—X-ray surgical table by Dr. R. Ledoux-Lebard (Gallot & Co.) made entirely of metal. Its height is adjustable by means of a bayonet arrangement in its legs. The height can thus be adjusted as required to suit the height of the surgeon, or if only one side is lifted it can be inclined as much as is desired for abdominal explorations.

the table of the type such as have been used for some years already by radiologists examining the digestive organs, especially the large intestine (for instance with a bismuth meal according to Aubourg's technique).

Béclère's table (Drault and Raulot-Lapointe) and Dr. Belot's new universal table fulfil all necessary require-

ments to a perfect degree. Without interfering to any degree with their transparency to X-rays and in order to make the surface more aseptic, it is possible to cover the top of the table with thin sheet aluminium (about 2 mm. thick will do).

X-ray Surgical Table.—If the method of examination to

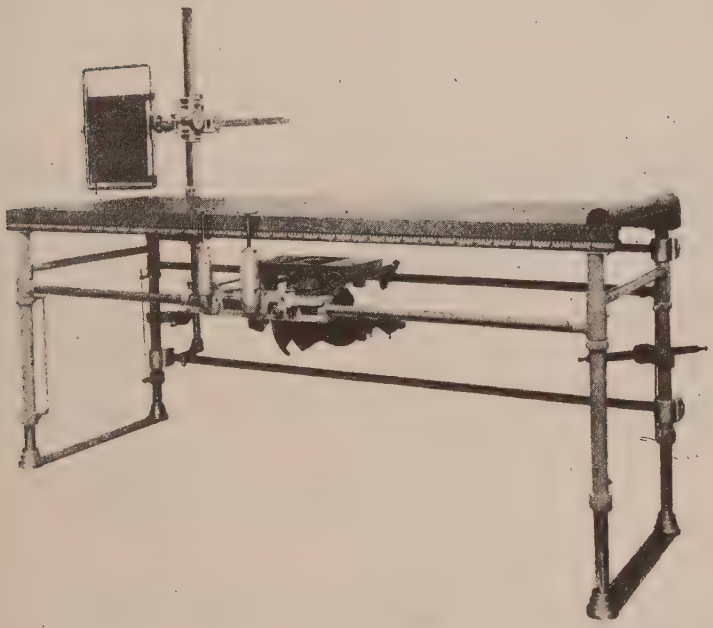


FIG. 69.—X-ray surgical table by Dr. Ledoux-Lebard (Gallot & Co.). Its frame is made entirely of metal and consequently very solid and perfectly rigid, whatever the height or the inclination adopted. The carrier is designed from the universal X-ray table by Dr. J. Belot and has all its advantages and is as easily worked. We see in this figure and in the preceding one the bathymeter by Dr. Dessane supported by a sliding arm which can also be used as a stand for the tube carrier and can be raised if required. In this sketch the legs have been purposely raised unequally at the ends.

be followed is that of extraction by means of the screen (see Chapter XII and following), and if it is necessary to operate constantly on an X-ray table, it is even advisable to use a table made entirely of metal, and one of our

colleagues has had a model of an X-ray surgical table made by Messrs. Gallot, which has the additional advantage, so much appreciated by the surgeon, of a movable top the height of which can be instantly adjusted (Fig. 68) and the surface of which can be inclined at will for abdominal explorations. We may mention here that in 1904 Dr. Haret submitted to the Congress of Milan a model of an X-ray surgical table which was the first really practical

FIG. 70.—X-ray surgical table by Dr. Réchou. It will be noticed that the arrangement of the legs allows of two different heights and a certain range in angle.

attempt to solve the problem which has now actually been done.*

Wullyamoz has also designed a model in which the whole plant for generating the rays was grouped on or under the table.

By adapting the movable X-ray appliance described at the beginning of this chapter to the X-ray surgical table we obtain an absolutely complete apparatus enabling us to proceed with the search for and localisation of projectiles. This installation which can be immediately connected to any electric light main offers the additional advantage of

* See Chapter XIII.

being easily portable from one room to another, from the X-ray room to the operating theatre.

Unfortunately, the price of the tables which we have just described, even that of the excellent table by Réchou (Fig. 70) built to a large extent of wood, and of the most simple construction, is rather high (1,000 to 2,500 frs.). The model of the table in the X-ray motor lorry outfit supplied by Messrs. Gallot-Gaiffe (Figs. 62 and 71) is of a more modest price and quite suitable, especially if the Delapchier appliance is adapted to it. But this obstacle is not insurmountable and those establishments which have only modest resources at their disposal should not allow this to stand in the way of adopting our method of extraction. With a little ingenuity and patience it is possible for most radiologists to construct with the labour at their disposal appliances enabling a tube and its diaphragm to be moved under the table and parallel to it.

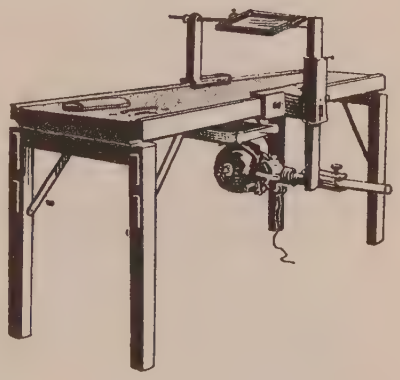


FIG. 71.—A simple table of the Gallot X-ray cars. The screen is carried on a movable holder.

Although X-ray tables thus constructed do not offer all the perfection and all the working facilities of those which we have described before, they are nevertheless quite sufficient in practice to be of great assistance. In the ninth district particularly very successful improvised couches of this description have been made by Messrs. Dauneau, Maillard and Taveneau. Fig. 72 shows one of these tables.

Every X-ray couch must be provided, for the purpose of screen examinations, with an appliance allowing the screen to be fixed at a desired height with movement in two directions parallel to the surface of the table. For the same reason it must also be fitted with stops enabling the tube to be moved an exact distance. These stops, which differ according to the models of the table used,

can be easily fixed and are at present supplied by every manufacturer.

It should also be provided of course with an adjustable rectangular diaphragm, and it would be as well to be able to add in certain difficult cases a diaphragm-opening as described later on (Chapter IX).

Apparatus for Screen Examination : Screen and Cryptoscope.—The fluorescent screen is one of the most indispensable elements in X-ray apparatus. But besides its classical form, which is too well known to admit of further description, and the 30 mm. × 40 mm. size of which represents

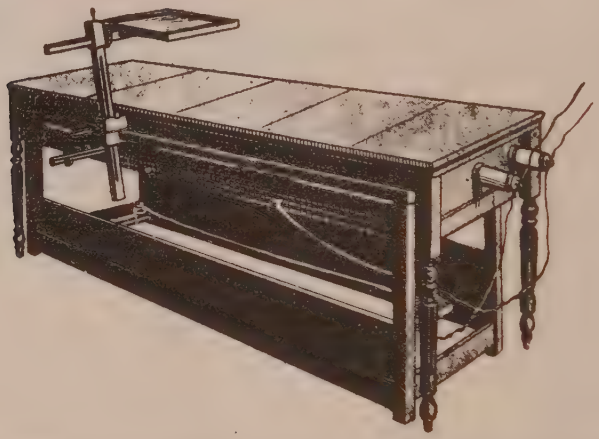


FIG. 72.—An improvised X-ray table designed by Dauneau.

one of the most suitable models we have seen, there has appeared in the course of this war, and rightly so, the revival of the cryptoscope, the *human eye-glass* invented at first by Segui and which is simply a small portable dark chamber fitted with a fluorescent screen. By its use the observer is able to adapt himself whilst remaining in a lighted room. He will thus be able to make an examination, to see a projectile in an operating room and guide the surgeon during his work if he operates on an X-ray couch. In its classical form it is represented by a box made in the shape of a pyramid. The bottom is taken up by the screen and the top is surrounded by a piece of material which enables the face to fit in closely and prevents any light

entering when it is applied to the head. This is effected by an elastic band which is passed over the head and keeps the cryptoscope tight; for this reason the latter is also called a band fluoroscope or cryptoscope.

Mr. Wullyamoz of Lausanne has invented a very ingenious fluoroscope which enables a screen examination to be made with one eye whilst the other eye is in the light. But as we shall see later on it is almost impossible to effect delicate observations under these conditions, and if a perfect observation is to be obtained the two eyes should be in the dark.

FIG. 73.—Radioscopic X-ray screen and fluoroscope by Dr. Réchou (Gallot & Co.).

FIG. 74.—Fluoroscope by Dr. Dessane (Gallot & Co.).

It seems to us that M. Réchou's fluoroscope made of leather (Gallot & Co.) is the lightest and the most practical of all the simple models (Fig. 73).

But if it is a question of an operation which lasts several hours it is very painful to have the face continuously hidden in the fluoroscope, the weight of which although slight is sufficient to become very inconvenient. Moreover, it is often of great importance for the radiologist to be able to *see* what is going on, and to follow the phases of the operation. But if he removes the fluoroscope he has not the

time (about ten minutes) for his eye to become sufficiently receptive again when the surgeon requires him. These rapid and repeated changes from light to darkness and vice versa are, moreover, very disagreeable and extremely trying.

Under these conditions the idea of wearing extremely dark-coloured closely fitting glasses naturally occurs to us. A pair of glasses similar to motor car glasses with india-rubber rims and either violet or brown lenses, very dark, and fixed over the head by an elastic band, may be worn without fatigue and enable the wearer to follow closely all that is going on in the theatre. At the desired moment the glasses can be slipped over the neck with the eyes closed and the fluoroscope is then adjusted. As soon as the screen observation is finished the operation is reversed: the fluoroscope is taken off with the eyes closed and the glasses are put on again. We have often adopted this measure during numerous and long operations in daylight and have never experienced the least difficulty in seeing the image on the screen.

But a pair of glasses constitutes an additional accessory. It may be forgotten or a glass may be broken. It is therefore preferable to have a hood which enables one to do without it. To achieve this it is sufficient to divide the hood into two parts, the lower of which contains the fluorescent screen and the upper one has a movable shutter fitted with very dark-coloured glasses. As soon as the screen observation is finished the lower part is taken off, and the upper part after lowering the shutter is retained and thus takes the place of a pair of glasses. Should the surgeon require the services of the radiologist for a minute, the lower part is rapidly fixed by lifting the movable shutter. Following these principles M. Bouchacourt has modified a fluoroscope which he had formerly invented, and to which he has given the name of Manudiascope, but as its use is much too restricted it is not very practical.

It is, moreover, a mistake to have pieces of apparatus which can be thus separated and placed anywhere. They have to be looked for when required, and they may have been mislaid. We therefore strongly advise the use of a fluoroscope (Fig. 75) designed by M. Dessane when in the Central Service of Radiology at Tours, and made by

Gallot & Co. Fig. 76 shows the radiologist with the bonnet on. As soon as he has finished his observation he lifts the lower part which stands up whilst the shutter of opaque glass comes down automatically (Fig. 76). The position of the hood when lifted does not allow the weight of the instrument to be felt so much as it leans against the head, as shown in the diagram.

This fluoroscope by Dr. Dessane seems to us to be the right instrument. Its size (13 × 18 cm.) is sufficient to enable the operator to undertake the search for projectiles

Fig. 75.—An X-ray examination with the Dessane fluoroscope.

which is indispensable—this not being the case with the manudiascope—and also it can be adapted for all purposes.

But some surgeons are deprived of competent radiologists. In this case they will generally be able to train one of their assistants rapidly in the art of handling the fluoroscope. As long as he has some notion of anatomy, and is intelligent, he will soon become an able assistant with a week's training. It may however happen that such an intelligent assistant is not available and that the surgeon must become his own radiologist, unless he wishes to forgo the benefits of screen examination. He is then faced by two opposing necessities. The first one is to see clearly and to have a good light if he wishes to be able to operate

easily in difficult places and in deep wounds. The second is to be in darkness or at least in an obscured light to be able to have recourse, if necessary, to screen examination during his operation. This shows that there is no really satisfactory solution of this problem ; he must resign himself to operating with difficulty under unsatisfactory conditions, which are often dangerous to the patient, if he remains in the darkness and contents himself with the fluorescence of the screen as a source of light. The same difficulties exist, although in a lesser degree, if he operates by a monochromatic light—for instance red—as advocated by M. Bergonié and M. Petit (of Château-Thierry), or violet as being theoretically excellent, not to speak of the considerable complications which would result therefrom.

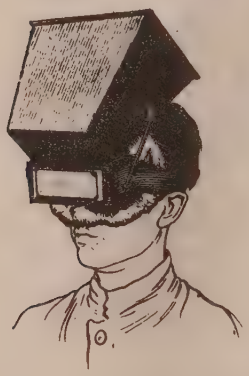


Fig. 76.—The radioscopic examination is finished. The radiologist has raised the lower part of the fluoroscope which leans against his head and he can see what is going on thanks to the deep violet glass which comes down when the lower part of the fluoroscope is raised. On the other hand, when the lower part descends, the glass "eclipses," leaving the view of the screen clear.

On the contrary if we operate in daylight the change from one to the other is no longer possible. We shall discuss this matter of technique later on (Chapters XII, XIII, XIV), but we think that the least unsatisfactory solution in that case is for the surgeon to operate by artificial light (ordinary electric light) and to use himself Dr. Dessane's fluoroscope, the glass to be chosen preferably of a violet colour not too dark. An assistant can lower it each time when it is necessary to undertake a screen examination, and then lift it on to the operator's forehead. With the aid of X-ray cars of the Gaiffe type, it will be possible to improvise almost anywhere, very easily and without any costly installations, operating rooms enabling examinations under the screen to be conducted under relatively satisfactory conditions.

To have an appropriate light it will be sufficient to make

use of a portable lamp with a conical reflector which an assistant can direct towards the wound. This method is much less disagreeable to the surgeon and to his assistants as it prevents the numerous accidents from happening which may be ascribed to monochromatic light, which may allow anæsthetic conditions or hæmorrhages to occur unobserved, and it avoids the considerable fatigue caused by rather long examinations made under this illumination, especially red.

We have also tested a double fluoroscope devised by M. Dessane (Fig. 77) which enables two people to carry on the observation. The surgeon is thus able, if he has no

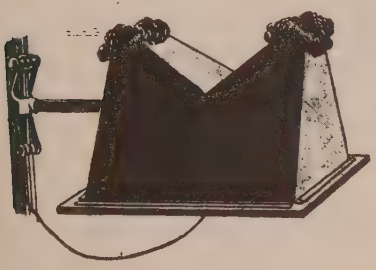


FIG. 77.—Dessane's double fluoroscope enabling an examination to be conducted by two observers at the same time.

FIG. 78.—An examination made by the radiologist and by the surgeon at the same time by means of Dessane's double fluoroscope.

experienced radiologist, to follow on the screen what is taking place. This instrument may be fixed on a stand or held in the hand, and Fig. 78 shows the way it is used. Later on (Chapter XV) we shall speak of various accessory non-radiological appliances for the exploration of projectiles, such as electro-vibrators, telephone probes, etc., which are however quite useless if a screen examination is available. A continuous rather powerful electro-magnet however may be very useful as an instrument for extraction in certain difficult and deep operations and especially for brain surgery. With this the existence of a continuous-current service of sufficient intensity is of course essential.

X-ray Appliances.—We are not concerned here with photographic material such as plates, papers, and all that

is required for their manipulation. We shall content ourselves with pointing out the absolute necessity of: (1) being very careful with the intensifying screens if we wish to make good use of them, and in order to prevent errors, (2) to use them only in cassettes which do not reverse the image. The aluminium cassette made by Drault and Raulot-Lapointe appear to us to be at present the best model of its kind (Fig. 79).

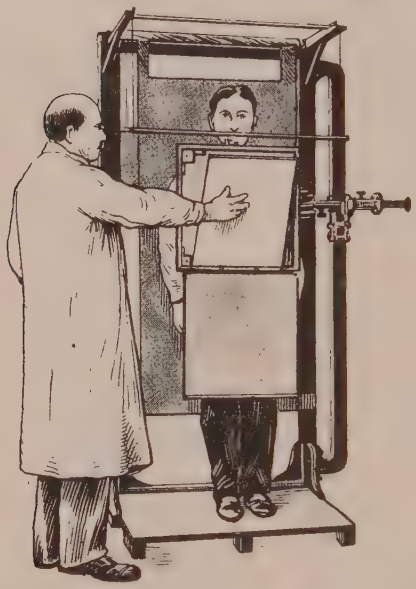


FIG. 79.—Magazine fluorescent screen fitted on a movable arm, adapted to a stand, suggested by Béclère and enabling the use of an aluminium cassette containing intensifying screens (Drault and Raulot-Lapointe).

§ 16. **Accessory Material.**—Finally we consider it necessary to mention some other accessories of which the negative viewing box is the most important.

The Viewing Box.—All those who have examined X-ray plates know that, in order to take full advantage of the negative and to study all its details, we must be able to look at it on a uniformly lighted background, the lighting intensity of which can be varied. Appliances constructed for this purpose (the most ingenious of which has been designed from particulars supplied by Dr. J. Belot) are called viewing boxes. But the high price of these appliances, especially in war time, prevents many X-ray installations from making use of them. In our opinion it is essential to examine all the plates with a viewing box, if we wish to avoid reading them imperfectly and omitting many important details. Such an appliance may be constructed without any expense with cardboard, for instance by aid of boxes in which X-ray plates are packed,

and a perfectly suitable viewing box may thus be obtained. A variable resistance may be added to it, if necessary, in order to obtain the required variation in intensity of light. Figs. 80 to 83 give the details for the construction of this apparatus, which may easily be fitted up anywhere and which was designed by Dr. Dessane. Its low cost will enable it to be installed in the operating theatres of the surgeon, who will be able during the operation to avail himself of the information thus provided by the plates.

We shall constantly be required to mark on the skin various important points required for localisation. This may be done by means of a skin pencil, but its marks

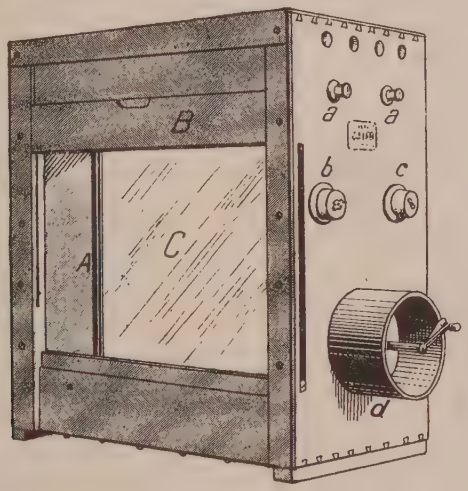


FIG. 80.—Viewing box of Dr. J. Belot.

disappear rapidly. It will therefore be necessary, if we require them to last several days whilst waiting for an operation, to mark them again either with silver nitrate or with a thermo-cautery. But the incandescent end of the latter often causes suppuration, and this may cause a septic place to develop which is not to be desired. On the other hand if the marking is light it sometimes disappears completely or else cannot be distinguished from many other cutaneous scars (acnæ, etc.).

Tattooing will generally be preferable and to that effect we strongly advise the use of Dr. Henry Béclère's tattooing

needles. They are immersed into a sterile solution of China ink and a cross or a point is made on the skin at the desired place with the needle which is sterilised in a flame after each patient.

As the mark is indelible this process must of course not

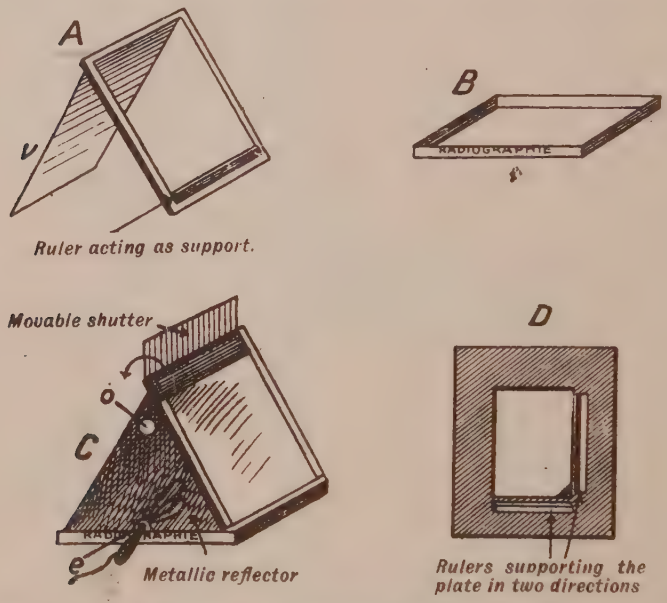


FIG. 81.—An improvised viewing box by Dr. Dessane. An old non-exposed plate is placed in the bottom *B* of a plate box (size 30 × 40 cm.). This will be used as a reflector and on it is placed an incandescent lamp of 50 or still better of 100 candle power. The lid *A* of the box is cut in the form of a shutter *v* which is moved back so that the lid takes the form of a trestle. To this is nailed a small ruler which carries another undeveloped plate or a piece of ground glass. We thus can obtain a uniform luminous surface on which we can place the plate to be examined. The diagram *C* shows the complete apparatus by sticking black paper, with white paper inside, on the free surfaces of the trestle. An opening *o* is made for air and an opening *e* for the passage of the socket of the lamp. On *D* are shown intermediate sizes of holders which are simply placed on the ground glass to receive plates of smaller sizes.

be used on the face or else only a very slight tattooing point should be made. The Pravas needle may also be used and a drop of China ink injected under the skin, but

this complicates the matter to a certain extent and causes

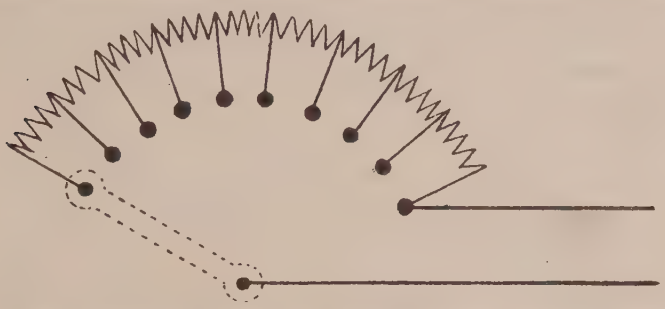


FIG. 82.—A simple model of a metal rheostat enabling the light intensity of the viewing box to be varied at will.

more work such as the sterilisation of the syringe, the needle, etc. Another appliance which is very often used in place of the skin pencil carried in a metal case, so often used by radiologists, and which necessitates considerable exposure of their hands to the rays, is the ink marker designed by Messrs. Gallot (Fig. 84).

Its long hollow stem contains a Bowden cable terminating in a wick soaked in dye. When the end of the stem is placed on the desired point a mark is made. We should add to our collection a few more accessories which, although not strictly radiological, will be found useful. First of all a meter rule together with a smaller ruler or a double decimeter ruler.

Callipers, compasses, a skin pencil, also a pencil which can write on the glass of the fluorescent screen or a stylographic pen will be very useful.

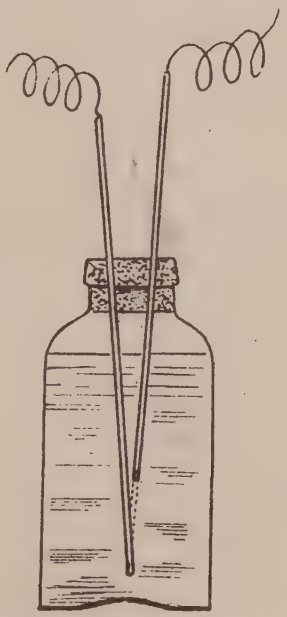


FIG. 83.—Another model of variable resistance for Dr. Dessane's negatoscope by means of a liquid rheostat, which is worked by increasing or lessening the distance between the two metallic rods (thick pieces of wire).

As we are now in possession of satisfactory apparatus and a well-regulated tube and of all the appliances we may require, we are in a position to commence our examination. As however we are going to expose ourselves to

FIG. 84.—A Gaiffe ink marker. A long and rather strong metal stem (30 to 40 centimeters long) or a wooden rod of the same length with a small lead ball attached to the end will often be found useful, but the spintermeter rod will always do instead. String, iron and copper wire, lead wire and a few sheets of lead rubber, combination pair of pincers, a screwdriver, a switch and adaptor which can be attached in any place when there is electric light complete all the necessary implements whenever it is required to make use of the electric mains. We need not mention here accessory electric appliances such as electro-magnets which are mentioned in a separate chapter (Chapter XV).

the action of X-rays it is essential that we should know the truly grave dangers which threaten us and what means there are of protecting ourselves against them.

§ 17. **Biological Effects and Dangers of X-rays.**—Everybody knows now that X-rays possess particular biological properties the knowledge of which has served as the basis of the enormous but as yet incompletely developed science of radiotherapy. Indeed X-rays have an effect on all living cells. Given the same cellular substance and the same quality of rays this action depends entirely on the amount absorbed. But all cellular substances are far from being equally sensitive. As far as human tissues are concerned the white cells of the blood and the cells of the testis and ovary are extremely sensitive, and the quantity of X-rays required for their destruction is infinitely small. Retinal cells and the malpighian cells of the cutaneous layer are also sensitive but require larger doses, whilst certain elements such as cartilaginous cells appear to be relatively immune. Moreover, speaking generally we may take it for granted that younger cells and also those cells concerned in reproduction are the most sensitive to X-rays.

Important researches, made on the basis of laws to which it is only fair to attach the names of Bergonié, Tribondeau and Beclere, give full particulars on these various points which we are not dwelling on here and for the study of which we may refer to the *Traité de radiothérapie de Belot*,* a very valuable source which since its publication has inspired numerous works which have appeared in German on that already vast subject.

It is these effects, mostly destructive and necrotic, which explain so many accidents imputed to the X-rays and about which we must say a few words. From the practical standpoint these accidents result especially in skin injuries, such as X-ray dermatitis, because although the cells of the skin are not the most sensitive they are nevertheless, as we mentioned before, sufficiently sensitive and they evidently receive such a much larger proportion of rays than other parts that the difference of quantity is sufficient to explain the relative frequency of their occurrence.

X-ray dermatitis may be acute resulting in an intense destructive action due to the absorption of a large quantity of X-ray radiations. It may be compared to a burn, and like this is of three degrees. It occurs mostly in patients exposed to X-rays, and especially after radiotherapy, which does not concern us, but it has become, for some years, so exceptional in radiography that there is no reason for fear, except in cases of a long examination, multiplied and repeated within a short time.

In civil life this only happens in the case of patients who intentionally conceal the fact, from the radiologist consulted by them, that they have been previously examined by X-rays by other specialists without his being aware of it, and even then an experienced physician, accustomed to question his patient closely, will as a rule become suspicious and take additional precautions. Unfortunately in military practice in time of war this is not always the case. Repeated examinations are, in fact, the rule rather than the exception, and it is difficult to avoid them in the absence of written documents sent with the patient when he is moved. Fortunately it is only very seldom that these examinations take place within a short time of each

* J. Belot, *Radiotherapie*, 2e ed., Paris, Steinheil, 1 vol. in 8°. A third edition is in preparation.

other, and as a rule the time interval is sufficient to ensure no harm being done, and although we have frequently seen patients who had been screened ten and twelve times, we have seen only two who have undergone multiple examinations (more than six) in less than two months. And nothing happened to them. As a rule it is the "curious case" or the difficult case, which is repeated, studied and shown on every opportunity, which runs risks. (Personally we have seen only two cases of dermatitis, even then only slight, in patients with difficult projectiles, who had been sent from one hospital to another.)

Although large doses of rays cause an acute form of trouble, a repetition of small doses during a long period is still more dangerous, because they act cumulatively without any sign or warning, until the day when there appears the condition of chronic X-ray dermatitis. All those who practised radiology during those times when this danger was ignored have made this sad discovery. In the end they noticed characteristic changes in their hands and especially on the back of their left hand which was constantly exposed to radiation, either for the purpose of showing to the uninitiated the X-ray appearance of a hand or especially in order to determine by that appearance and by the degree of contrast of the image seen on the screen the degree of softness or hardness of the tube. This chronic dermatitis manifests itself at first by a state of dryness and particular roughness of the skin with constant itching, by the falling out of hair on the skin, by a brittleness of the nails and then by their loss, and by the appearance of small cutaneous and very painful cracks, by hard nodules and by small epithelial warts. It is on these that there very often develop those cutaneous epitheliomata the frequency and spreading tendency of which render it so difficult to give a prognosis on the professional injuries of radiologists. This prognosis is the more difficult because once affected by the rays the affected tissues not only do not become immune, but on the contrary become more sensitive as if some singular anaphylaxis had taken place. Thus once established a radiologist's injuries do not tend to recovery. Whatever the precautions taken by him the infinitely small doses of rays which he receives are sufficient to maintain the injury of which in the early stage he can be

completely cured only by giving up his profession definitely —or at least for many years.

It is because they remained so faithfully attached to their profession that about a hundred radiologists have become victims to neoplastic changes in their injuries and that so many others only owe their existence to numerous early and mutilating operations.

Once we know the danger we must to start with take precautions to avoid it; we consider that this is possible without neglecting any branch of radiology and without renouncing in any way radioscopy—this essential cause of accidents, because it is in this way, especially when examining a patient standing, that the observer is exposed to the direct and very close action of rays emanating from the anticathode.

In fact, we have seen when studying the principal physical characteristics of X-rays (Chapter II) that they can pass more easily through bodies of lower than higher atomic weight. If we place ourselves inside a cabin the walls of which are lined with sheet lead of sufficient thickness (3 mm.) we shall be practically protected from any danger.

But although we may be able to have access to that absolute remedy in some of the large and perfectly organised services, it could not be used as a general proceeding especially in war time. Its application would moreover be restricted by the fact that, although it is easy to place in a leaded cabin all the necessary articles and to remain there whilst the plates are taken or during treatment, it must be left in order to undertake radioscopic examinations which, as we have seen, are the principal source of danger. If we renounce these we take off at least half of the value of radiology, and no real physician or radiologist would or could do without these. Generally it would be sufficient to shelter during the taking of radiographs or during radiotherapy, behind a screen opaque to X-rays (Figs. 85 and 86). We consider however that even in continual daily practice the radiologist who is always careful and takes all the precautions which we are about to enumerate, may for many years be unaffected provided that he has not been yet affected.

If we place the tubes into opaque shields (as seen in

§§ 10 and 14) we limit the outlet for rays to the opening in these shields. The constant use of a diaphragm the shutters of which are also opaque should still more reduce the injurious beam and restrict it in such a way that the area covered does not attain and especially never exceeds the limits of the fluorescent screen. The latter, consisting of a salt of a rather high atomic weight, stops in itself a very important proportion of rays, but we must always cover it with lead glass, and we must arrange on its two ends two handles protected by metal shells in order to protect the hands which hold it.

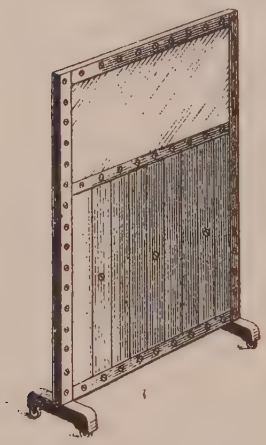


FIG. 85.—Screen opaque to X-rays.

We also advocate the systematic and extensive use, at all X-ray proceedings, of an aluminium filter (2 to 3 tenths mm.) which does not in any way interfere with radioscopic vision or with the beauty of the plates, but protects the patient and operator against that softening of the tube which is so dangerous to the skin, because soft rays, being mostly absorbed by the surface, are the most dangerous to the skin.* Thus the quantity of harmful rays reaching the observer during the

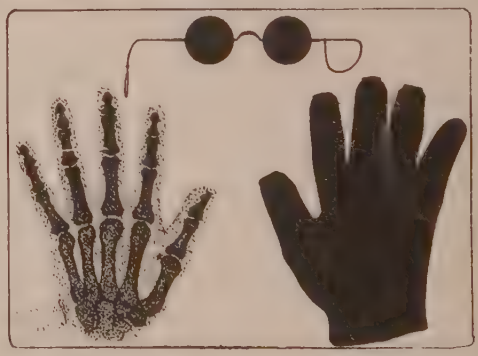


FIG. 86.—A radiograph of spectacles and of gloves opaque to X-rays.

* One of our colleagues has published recently (*Société de Radiologie*, 1914) a very simple device designed to that effect by M. Drault. Whatever the apparatus used an aluminium filter can easily be placed between the source and the patient.

examination will be extremely weak and will be reduced to some thousandths of the original radiation. If moreover he protects his eyes, which are sensitive organs, by means of spectacles of lead glass, the best model of which is the type of spectacles with large glasses (similar to motor car spectacles, produced by Messrs. Gallot according to particulars supplied by Dr. J. Belot), and if he wears an apron of opaque material, then he will have protected sufficiently the most sensitive portions of his body, and will have run no danger whatsoever. Now, as regards his hands. They are the most exposed parts because, being generally required for various manipulations, they are nearer the tube than the rest of the body (law of the square of the distance) but especially because certain examinations require manipulations behind the screen and thus they receive the rays directly. They must therefore always be covered with opaque gloves, but the usual type which only protects the back of the hand does not seem to us to be sufficient. We therefore advocate the use of gloves which have two thicknesses of opaque material at the back and one on the palm side. Of course they are not supple, but here again we find ourselves with two contrary necessities, suppleness on the one hand and opacity to the rays on the other, but it is the latter which is the more important, as it is on the latter that the protection of the hands depends. By this we wish to say that those surgeons who are tempted to operate under a screen by exposing their hands will have only an illusive protection by covering them with an opaque paste such as is advocated by M. Mauclaire. They will only have themselves to blame if they contract some injury, when there are simple appliances which protect them absolutely by preventing any contact whatsoever with the rays (Chapter XIII). Need we insist on the necessity that the radiologist should only expose his hands, even gloved, to the direct action of X-rays in cases of absolute necessity and then as seldom as possible ? In fact, in spite of all the precautions and the thickness of the opaque materials used by us, a small quantity of very penetrating rays will always reach them, and a repetition of these weak doses will be sufficient to constitute a danger.* By this we

* It is impossible to discuss the whole question in detail, because

mean to say that the radiologist who practises the search for and localisation of foreign bodies must not use skin pencils with metallic cases—these are too often used for the purpose of marking the points on the skin under the screen. This necessitates a direct exposure of the hand to the rays, whilst by using a long stem such as the Gallot marker or any other appliance (§ 15 and Chapter VIII) the result is obtained without any contact with the rays. In the same way when trying to move foreign bodies by palpation under the screen, a sufficiently long rod should be used (generally the rod of the spintermeter will do).

To sum up: The hands must never be placed under the screen in the path of the rays if it is possible to avoid it. By proceeding thus and by remembering all the precautions we have enumerated, we think that radioscopy can be practised without danger, even every day and for long sittings, provided of course that the protection used is real, that is to say that the opacity of the spectacles, gloves, apron, shields and especially the lead glass of the screen have been tested (the glass must be at least 3 mm thick, a fact not often observed in most instances).

Once we know how to protect ourselves we may pass to the practical use of the apparatus with a view to finding and localising foreign bodies in patients entrusted to us for examination.

in this rapid survey we do not touch at all on the action of secondary radiation which in practice is, however, insignificant.

CHAPTER V

SEARCH FOR FOREIGN BODIES. CONFIRMATION OF THEIR PRESENCE OR ABSENCE. CAUSES OF ERROR

§ 18. **History of Case and Clinical Examination.**—A rational X-ray examination of any subject supposed to have a foreign body in him must in the first place be clinical. It should be a short but precise examination. Without attaching too much importance to all that the patient states, the radiologist will make the patient tell him in a few words the principal events: date of the accident, nature of the agent that caused it, situation of the wound of entry if already effaced, complications, etc. He will inquire carefully as to any former X-ray examinations, trying to find out if possible their precise number, result, nature (radioscopy or radiography), the radiologist who made the examinations, and especially the date of the last one, in order to avoid the effect of cumulative doses (causing dermatitis) should it have taken place too recently.

Written documents on the subject will, of course, dispense with a part of this examination. But in war time it is extremely rare to find any useful written documents. Very often one has to go by the particulars supplied by the patient. Sometimes the hospital notes or the observation chart mentions: "X-ray examination." As these documents do not contain the name of the radiologist, and only indicate the result of the examination in very exceptional cases, and even then insufficiently, this evidence is generally valueless. The examination must therefore be always commenced afresh and very often patients are seen who have been examined with the screen or radiographed more than ten times and who have to be examined again. This repetition of examination which is very costly to the State and possibly dangerous to the patient can only be avoided

with great difficulty. This subject will be discussed later on and we shall then indicate what precautions we take to remedy this defect.

If radiographs, tracings, etc., have already been taken but they are not as clear as might be desired, or if there is any doubt as regards their definition or their authenticity, another examination must always be made especially with regard to military patients. Under no circumstances must the statement of the patient be taken for granted as to the presence or absence of a projectile.

A rapid examination of the patient by feeling carefully the skin, by looking at the places where the projectile or projectiles entered and left and by taking into account the principal functional troubles will often lead to some presumption as to the site and nature of the foreign body. But the absence of a visible place of exit will not be a sure indication that there is a retained projectile, just as the absence of a perceptible place of entry will not prove that a projectile is not present. Nothing but a complete X-ray examination will enable us to make a definite statement to this effect.

§ 19. **Undiscovered Projectiles** are extremely common. Whilst some patients complain in quite good faith of considerable and generally subjective pain on account of very small fragments of metal retained in places which anatomically might be considered to be innocuous, radiologists who have examined wounded soldiers know how often it is possible to discover projectiles, even very large ones, which had not been suspected by the patient to be present. This is mostly the case with rifle or machine gun bullets which may have penetrated without causing any pain, and which are generally tolerated much more easily than fragments of shell

Fig. 87 shows a German bullet which was retained in the first interosseous space and was discovered during a radiographic examination of the hand undertaken for the purpose of verifying the state of the fourth metacarpal struck by a piece of shell which had been previously extracted.

Figs. 1 and 2 of Plate I. which is still more singular, show an almost complete German bullet, deformed only at its base, which was lodged in the right maxillary sinus without

any clearly visible wound of entry and without its presence being suspected by the patient.

It happens still more frequently that projectiles are found in situations which are very distant from the wounds of entry and from the region in which the patient locates the pain due to their presence. One of our colleagues published, together with Mr. A. Gosset, in 1914 a very curious example before the war started.*

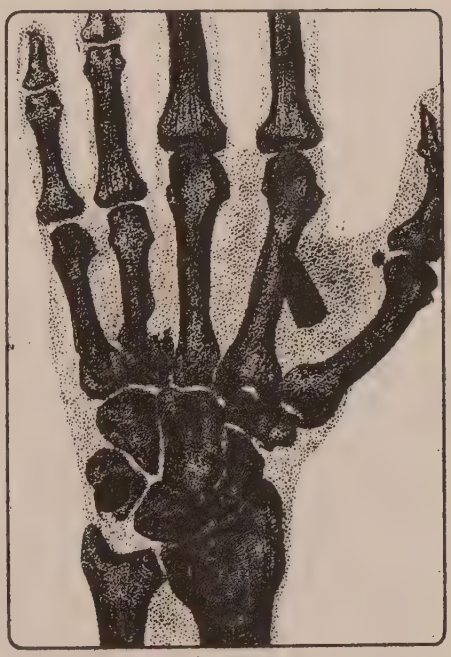


FIG. 87.—Radiograph of the right hand, seen from its palmar surface. A German bullet projects at the level of the first interosseous space. This man was wounded by a machine gun and a bullet had already been extracted from the front part. He never suspected the presence of the second projectile which has probably entered through the same orifice as the first to which no doubt was due the fracture of the fourth metacarpal. The appearance of the pisiform bone should be noted as it could easily be taken at a first glance for a shrapnel bullet. The sesamoid of the thumb should also be noted and also that of the fifth metacarpal seen through the head of that bone.

The case was that of a young girl who shot herself three times with a revolver, one shot lodging in the præcordial region. Although the orifice of the entry of the latter was clearly visible and there existed indisputable clinical signs of hæmothorax, the screen examination, which it is true was made rather hurriedly owing to the grave state of the patient, did not show the projectile, neither did it appear on the plate. After her recovery the patient

* A. Gosset et R. Ledoux-Lebard, *Bulletin de la Société de Radiologie*, 1914.

was again examined on the screen this time very thoroughly, again without success. Plates from the head to the pelvis were all negative. The plate of the pelvis being rather faint was taken again on a larger plate which included also the top part of the thighs. The bullet was found at the bottom of the left thigh in the adductor muscles. It seems that it could have lodged there only by taking a sinuous course which we shall not try to explain

Similar appearances not less paradoxical often take place with our wounded men, and the force of penetration of projectiles easily explains that a bullet or a fragment comes to rest at a great distance from the point of entry, and is able to penetrate almost the entire length of the body. Similar occurrences do not surprise us nowadays.

An examination is only complete when a patient has been examined from head to foot, and this practically can only be done by radioscopy.

§ 20. **The Radioscopic Examination.**—The first examination to be made is of course radioscopic. It should naturally start with the suspected region, and it is only after being carefully explored without results that all the other parts of the body should be examined successively if the examination is to be complete.

Besides anomalous projectiles to which we have alluded before we find, in the course of this war, numerous examples of patients with multiple projectiles, and some men are, so to say, filled from head to foot with metal fragments (see Figs. 88 and 89). With the advent of trench warfare which has generalised the use of grenades, aerial torpedoes, etc., these cases have become more and more frequent (see several diagrams on our plates). The possibility of rapidly and completely exploring a body in all its entirety is not one of the least advantages of radioscopy. It is therefore surprising that in a great many units projectiles are still looked for by taking radiographs, resulting in long and costly examinations which often yield no results as very often the projectile is not on the plate. And one would not obviously attempt to take radiographs of every wounded man from head to foot. Although it is not possible on active service to make a complete screen examination of every patient, it is at least easy to undertake an exhaustive examination of those who show symptoms which are not

explained by a clinical examination, and when a projectile has not been found in the region of the wound.

It is necessary therefore to protest vigorously against the ban which has been so often pronounced against screen examinations in spite of the constant teaching of M. Béclère and of the meritorious efforts of our eminent

FIG. 88.—Radiograph of the right shoulder seen from its posterior aspect. (It will be noted that the external extremity of the clavicle has been fractured and some parts are missing.) Eight metal fragments of rather a large size can be counted in the region of the shoulder. The wound was caused by a shell.

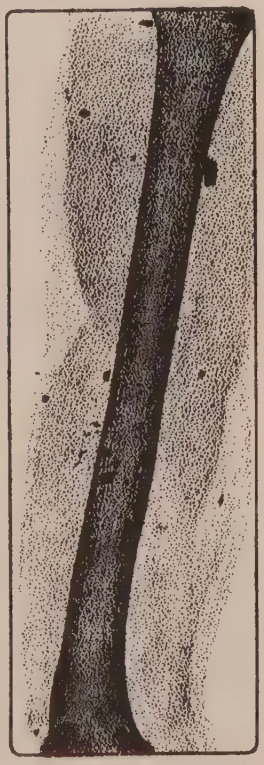


FIG. 89.—Radiograph of the left arm seen from its posterior aspect. Multiple metal fragments disseminated in the soft parts (grenade).

colleague and friend Haret. This is not only the case in France, but also in Germany. The disfavour into which it has fallen may be explained by two principal reasons :

(1) Many radiologists and most surgeons imagine because many projectiles escape their screen examinations made too rapidly and with imperfect appliances that a screen examination shows only foreign bodies of a large size situated in transparent regions.

PLATE I

FIG. 1.—Radiograph of the left knee seen from its outer side. We notice in the soft parts behind the shadow of the femoral condyles a metal fragment of the size of a pea. The appearance of the tibia should be noted. This is not as we might at first be led to believe an injury to the bone caused by a projectile but the point of ossification of the tubercle of Gerdy (patient nineteen years old).

FIG. 2.—Radiograph of the left knee seen from its outer side. In the soft parts behind the condyles we see the shadow of the sesamoid of the knee which must not be taken for that of a projectile or of an abnormal bony loose body. There is a fracture of the patella with a metal wire surrounding it. The wire is broken. By comparing the two plates (1 and 2) we shall notice that it is the difference between the intensities of the shadows which enables us to distinguish the projectile from the sesamoid. (See also Fig. 98, p. 125.)

FIG. 3.—Radiograph of the left hand seen from the back. A metal fragment of the size of a pea is seen at the level of the head of the fourth metacarpal. Small pieces of metal wire from a grenade which has caused the wound will be noted in the soft parts between the lower parts of the articulations of the middle and ring finger.

FIG. 4.—Radiograph of the forehead seen in profile from the left side. Very small metal fragments will be noticed at various points. The large opaque body of which the shadow is seen in the orbit is not a piece of shell but a glass eye (made of lead glass).

PLATE I

FIG. 1

FIG. 2

FIG. 3

FIG. 4

(2) The very justifiable fear of radio-dermatitis degenerates too often with radiologists into unreasonable alarm which keeps them from employing this method and they communicate this fear to the surgeons. We shall not dwell here on this second point which has already been dealt with in Chapter I and which we shall discuss later on (Chapter XIII), but shall consider here only the first reason. It will be very easy to demonstrate that it is fallacious.

Visibility of Projectiles on the Screen.—Its Conditions.— Our personal experience which is now based on the minute examination of over 5,000 wounded men enables us to affirm that with the exception of the eyeball (Chapters XI and XIV), and perhaps of some very rare cases which we have not yet encountered of particularly opaque subjects, every projectile the extraction of which may reasonably be undertaken by the surgeon, that is to say which has a diameter of at least 3 millimeters and which consists of any metal but aluminium, can always be seen on the screen, even in the thickest part of the body, the cranium, spine or pelvis. But in order that this may be done it is necessary—and it is sufficient—that the examination is made by a competent radiologist according to certain conditions.

There are three conditions which we shall explain successively and which contribute to the increase or diminution of the radioscopic visibility. These conditions depend:

(1) On the apparatus.

(2) On the nature of the body looked for.

(3) On the operator.

(1) *Conditions depending on the Apparatus.*—We have already examined these conditions in §§ 14 and 15, in sufficient detail. It is therefore unnecessary to dwell upon them and we only wish to state again that almost all instruments which are now being constructed enable one to make all the screen examinations necessary for finding projectiles in a perfectly satisfactory manner, because to do so it is only necessary to have one to one and a half millis with 10 to 12 cm. of equivalent spark, as long as we have at our disposal a good and well-seasoned tube (Chabaud or Pilon) and the appliances necessary for the manipulation of the diaphragm.

The X-ray cars which have been mobilised since the war

PLATE II

FIG. 1.—Radiograph of the left shoulder seen from the back. Rifle bullet (German) which is embedded base first in the head of the humerus. Its intra-osseous position can be diagnosed almost with certainty from this plate alone, owing to the presence of a very sharp area of rarefaction of the part of the humerus which corresponds with the bullet (verified by operation).

FIG. 2.—Radiograph of the left thigh seen from behind. Pocket revolver bullet lodged in the soft parts of the antero-internal aspect of the thigh.

FIG. 3.—Radiograph of the left knee seen from its inner side. We see a projectile which seems to be embedded in the tubercle of the tibia by its base. The projectile seems to have penetrated base foremost (the wound of entry was in front of it in the skin at the same level) and is of a singular shape (? a projectile purposely deformed by the enemy).

FIG. 4.—Radiograph of the right leg seen from its inner side. We see embedded in the soft parts behind the fibula the shadow of a metal fragment which was only a piece of the ring of a suspender worn by the patient. This indirect projectile was driven into the tissues by the explosion of a grenade which made a serious wound in the calf.

FIG. 5.—Radiograph of the left thigh seen from behind. We see towards the neck in the middle of the inter-trochanteric line the shadow of a slightly misshapen shrapnel bullet. The great trochanter shows on its outer border traces of a perforating injury. Small pieces of metal, evidently detached from the shrapnel bullet, cast their shadows over the whole surface included between the external border of the large trochanter and the projectile. This information enables us to conclude that the bullet is in all probability within the bone, although no area of decalcification is apparent. We have noticed that this decalcification is much less accentuated and very often totally absent in cases in which the projectile is a bullet (verified by operation).

FIG. 6.—Radiograph of the right lumbar region seen from the back. The shadow of a very large metal fragment (piece of a shell) is seen in the soft parts at the level of the second and third lumbal vertebra.

PLATE II

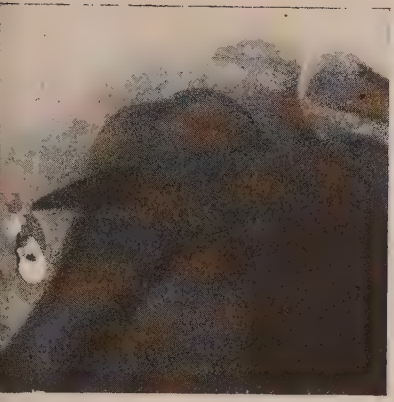


FIG. 1

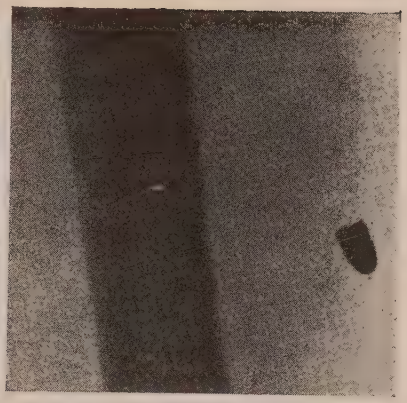


FIG. 2

FIG. 3

FIG. 4

FIG. 5

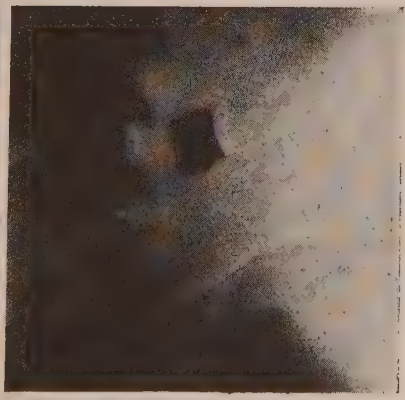


FIG. 6

started are of course perfectly suited to this kind of work and especially lorries of the Gaiffe type.

We need not speak here about the room required it must evidently possess the general conditions of lighting and space needed for any screen examination.

We also know that it is possible to undertake screen examinations in rooms illuminated either by daylight or by artificial light if we use the fluoroscope which we describe in § 15. But although this very useful appliance is quite sufficient for finding large projectiles or for following during a surgical operation a metal fragment of a very small size, the position and shape of which are however known to us, it is not adapted to all the requirements of a first exploration in difficult cases, for which the radiologist must not only be in a condition of good visual receptivity, but must also have means of examining large segments of the body at the same time and in addition every liberty of movement so as to be able to carry out all the various accessory manœuvres required. Therefore the use of the fluoroscope, which has its definite uses for the extraction of projectiles by means of the intermittent control of the screen, is restricted to the search for a projectile relating to urgent cases and can only be used exceptionally for complete and definite examinations.

To sum up: conditions favourable to radioscopic vision while depending on the installation, on accessory material and on the provision of suitable premises, can almost always be easily obtained anywhere.

(2) *Conditions depending on the Nature of the Bodies looked for.*—We have already seen several times (Chapter II) that with the same thickness the transparency of various bodies to X-rays depends upon their atomic weight and diminishes proportionally as it increases, whilst with an equal atomic weight the transparency diminishes in the same degree as the thickness increases. If we express in figures the degree of relative transparency of bodies and if we take into consideration their atomic weight and their thickness we shall find that a shrapnel bullet or a bullet from a German or French rifle is quite visible in view of its relatively considerable opacity to X-rays in any part of the body, to an observer working under good technical conditions (the most important of which is the visual

adaptation) and who is conversant with this kind of examination. In fact, very simple calculations based on transparency tables of equivalents published by Mr Benoist show that $\frac{1}{10}$th of a millimeter of lead, $\frac{4}{10}$ths mm. of iron, 8 mm. of aluminium or 45 cm. of soft tissues will project on the screen a shadow of the same intensity. If therefore the diameter of a shrapnel bullet is 1 cm. 45 cm. of soft tissues would have to be interposed between the shrapnel and the screen to produce the same opacity of shadow. The shadow produced by the shrapnel bullet covered with such a thickness of soft parts should still be visible, because it should have a double intensity according to the absorption of rays by the 45 cm. of soft parts and by the shrapnel bullet. But two troublesome phenomena interfere. The first one is that starting from a certain intensity of shadow, it becomes difficult to distinguish on the screen degrees in that intensity. The second one which is the most important is that the image becomes blurred owing to the production of secondary rays, and the more soft tissues there are interposed and the harder the rays used the more intense does this become. It may therefore be considered that in practice as regards thick parts a projectile ceases to be clearly visible on the screen if it is included in soft parts the opacity of which, whether resulting from their thickness or from their atomic weight, is equal to that of the projectile.

It is evident that other things being equal the visibility will diminish with the atomic weight of the metal of which the projectile is composed and with its size. But, with the exception of aluminium the employment of which in the fuses of shells is known to all from the rings made from it by the soldiers in their leisure hours, there are only heavy metals which are now used in the production of bullets and of various parts of shells, such as lead, brass and iron.* Therefore we only must take into account the sizes of the projectiles retained. If guided by the above-mentioned figures we take a piece of lead the thickness of which is supposed to be at least 1 mm. in its largest diameter or a piece of iron the largest diameter of which is 4 mm. we see that 45 cm. of soft parts will be required to produce an

* We have not seen yet on the French front glass bullets the use of which has been mentioned on the Russian front

equivalent shadow before we shall lose the shadow of the foreign body from the quantity of the secondary rays produced. And there can hardly be a case in whom we should have such a thickness of soft tissues interposed between the projectile and the screen. And should even such a thickness exist there is always a direction in which the thickness is less and the patient should be moved into different positions to find it and it should be possible to obtain on the screen a shadow of the projectile which is more accentuated than the shadow of the surrounding parts.

Similar calculations also show that if bony structures intervene it will be necessary to have such a thickness of calcareous tissue to absorb the radiation to the same degree as the metal fragments that they can always be seen, as previously mentioned, whenever it is a question of projectiles the dimensions of which are such that operation is indicated. (It will take 53 mm. of bone to give the same shadow as 1 mm. of lead or 4 mm. of iron.)

(3) *Conditions depending on the Operator.*—These are of a very different nature. We have already studied in detail the conditions of visual receptivity, and have shown the absolute necessity of staying in darkness before commencing any examination. The importance of this is such that we cannot insist too much on it. Insufficient receptivity is even now the principal cause of the want of confidence in screen examinations shown by a certain number of radiologists and by many surgeons who always hard pressed for time have never had the leisure to conduct completely and under favourable conditions a search for a projectile with the screen, and who having themselves seen nothing on the screen can very often hardly believe that others could have been able to do so except with the eye of faith. But even if the observer's eyes are in a suitable state of receptivity we must still take into account his personal capacity for this observation. We have seen that there are considerable individual variations in visual acuity in dark surroundings. If we except real "night blindness" which alone would constitute a real obstacle to his ability to undertake the study of radiology because in this case he would be incapacitated from making any screen examination, we may consider these variations can be

almost always overcome by a sufficiently complete preparatory adaptation, so that in practice this need not be taken into consideration. It is thus evident that the value of an examination will depend upon the experience and personal knowledge of the radiologist and especially from his mastery of radioscopic technique.

§ 21. **The Radioscopic Technique.**— As in any other medical application of exact science the technique of the examination on the screen plays an important part provided good accommodation is realised. We must know how to look for the foreign body. To do this efficiently the patient must be examined not only in one position but the suspected region must be placed at every possible angle, both by moving the patient and by moving the tube.

We shall thus clearly recognise the position in which the foreign body under examination is most easily seen, whether it is in its longest diameter or in the axis in which there is the least interference from body or soft parts.

But one of the most important points in the examination lies in the manipulation of the diaphragm, the use of which is indispensable and without which it is absolutely useless to undertake a systematic search for projectiles by screen examination.

Let us remember that it is only its judicious use which enables us to eliminate a part of the secondary radiation, an essential cause of trouble and of absence of clearness in screen images, the absence of clearness being the more evident in the regions where the soft parts are thickest. The narrower we make the pencil of rays the clearer the image will be. The use of the diaphragm which is necessary for finding projectiles will also be shown necessary for the localisation of projectiles and we shall also demonstrate the difficulties of satisfactory vision which interfere with its use in certain methods of radioscopic localisation.

A complete examination search for and study of projectiles can be undertaken with the patient lying down. It is however extremely convenient although not indispensable, especially for intra-thoracic projectiles, to be able to examine him also standing when it is much easier to keep him in various oblique positions which may be needed. It must not be forgotten that a projectile, even a very large and opaque one such as shrapnel, if it is placed in the walls of

the thorax in such a way that it coincides with the shadow of superposed ribs could perfectly well fail to be seen on the screen, the thickness of the bone being then represented by the superposition of the segments of the rib under consideration, which thickness may exceed 10 cm. and thus reach, especially if we add rather thick soft parts and an intense secondary radiation (very open diaphragm), the limits fixed by our previous calculations for the visibility of a projectile on the screen.

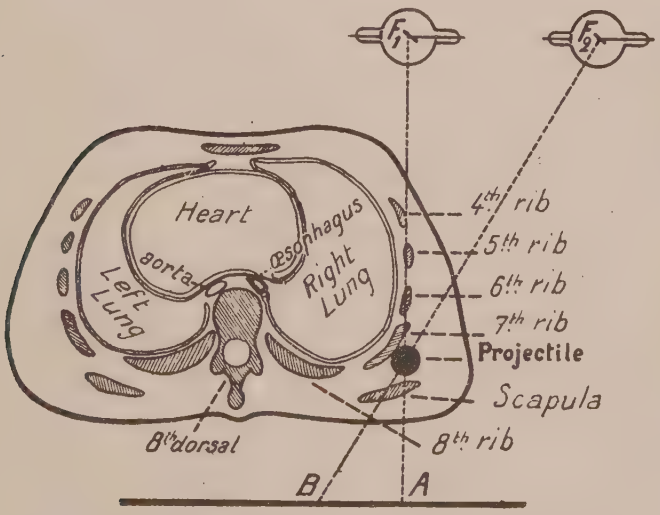


FIG. 90.—This diagram represents a section of the thorax passing through the eighth dorsal. We see that the ray F 1 A must traverse, before reaching the projectile, segments of the fourth, fifth, sixth and seventh ribs, and a considerable thickness of soft parts as well as the scapula. It is therefore not surprising if the projectile is not visible at this angle whilst it would be easily visible in the line F 2 B.

Very often by making the subject breathe deeply so as to lower the diaphragm or by examining him laterally we may discover standing out in the clear pulmonary area a projectile which may have passed unobserved in the shadow of the dome of the diaphragm as shown on the diagrams in Chapter XI. These various manœuvres will also enable us to show in numerous cases thin metal films which would only give a clear shadow if seen edgeways, as

the interposed thickness of the metal in front of the screen would be sufficient to render them quite visible.

The head should always be examined not only from the front but also and especially from the side and if necessary at various angles.

There are in almost every region little technical rules all of which tend to increase the visibility and which are all very simple, but which require a real training on the part of the man who is carrying out the examination if they are not to be forgotten and if they are to be applied more or less mechanically and quickly. One is thus sometimes quite surprised to see an experienced radiologist find the projectile immediately during a screen examination where a novice has been trying to find it for a long time and in vain. We shall have an opportunity of discussing all these details again when we shall study the marking of projectiles for each special region (Chapter XI).

§ 22. **Radiographic Examination.**—We have said that every projectile which can be extracted surgically is visible on the screen. But should a screen examination, even well conducted and under satisfactory technical conditions, not have shown a foreign body, this does not prove that one is not present. It only enables one to be almost certain (if the examination has been undertaken by a competent physician-radiologist) that the patient has no large projectile in any region and to be quite certain of its absence in transparent and easy regions such as the limbs. But even for limbs and in any case for the thorax and the abdomen one must be careful not to come to a too hasty conclusion and state only—if the examination is not being continued—that from the screen examination no projectile was visible. The examination may have been carried out under unfavourable conditions, due to defective apparatus (the tube being too soft which there was not time to harden or the tube being too hard), to fatigue or a hasty examination on the part of the operator (a large number of wounded have to be seen in war time in certain emergencies) or to the projectiles being very small or the patient being very thick, etc.

It has often happened that one of us has found projectiles after a screen examination where other radiologists have previously made a negative examination and it is

quite probable that some projectiles have been missed in rare cases where a negative diagnosis has not been verified by a plate. Moreover as we have previously shown in § 7 a plate possesses an X-ray sensitiveness which the human eye placed under abnormal conditions of work cannot equalise. The plate will thus supply details which may completely evade our eye.

For this reason it is a valuable and indispensable adjunct to every screen examination. If the examination has been negative it ensures that no important fragment has escaped and shows the number, position and shape of the small fragments or pieces of dust which may exist without being visible on the screen ; if it is positive and especially in case of projectiles of which the extraction is likely to be difficult it supplies additional particulars as to the state of the bones or of the surrounding soft parts, etc.

Without in any way entering into details of radiographic technique, which would be out of place here and for which the reader should consult various books of radiology and especially the excellent hand-book of Jaugeas, we wish to point out that to obtain good plates easily it is essential to use soft rays and to immobilise the patient completely. Almost all the existing installations even the simplest ones enable anyone with a good technical knowledge to take extremely satisfactory plates of the limbs and of the head the taking of which does not in any way necessitate powerful installations. Even for plates of the thorax, kidney, intra-abdominal viscera in apnœa X-ray cars can be quite satisfactory. It is only for projectiles with communicated pulsation requiring, if it is desired to obtain sharp images, instantaneous radiographs that the most powerful and most modern installations are necessary.

§ 23. **Reading of the Plates.**—(Refer to Chapter III) It is extremely important to obtain in every case plates which are technically faultless, because they will become a source of information very often of extreme value if they have been well taken, well examined and especially correctly read.

In the case of a positive examination a plate gives us information with regard to the number, the shape and the nature of the projectiles.

The Number.—This is evidently necessary ; at the same time it must be pointed out that a group of adjacent projectiles or even two projectiles lying at a great distance from each other may only figure on the plate as a single projectile if, at the moment of being radiographed, they lie on the line of the same normal ray (Fig. 91). This happens very rarely but the possibility of such an eventuality should not be forgotten.

The shape and the nature of the projectile may be inferred

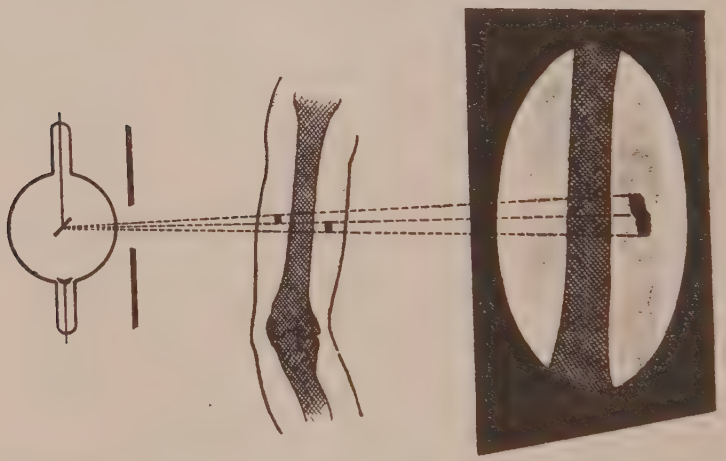


FIG. 91.—This diagram shows how two small projectiles may give a single shadow and simulate a larger projectile.

to a certain extent from the examination of the plate, and this is a consideration of some interest not only from the medico-legal standpoint but also from the operative point of view when it is necessary to know whether it is a question of a magnetic projectile or not, which is sometimes of importance in selecting the technique to be employed for its extraction.*

* The shape which most often gives valuable information as to the kind of projectile with which we are dealing—German or French bullet, shrapnel, fragment of a shell, etc.—and consequently also as to its nature, must of course be deduced from the appearance of the shadow with all reserve imposed by the knowledge of projections of a body of three dimensions on a plane, according to the laws, previously referred to, of authogonal projections.

In reality it would be necessary to be able to supply more correct

The nature of the metal is deduced from the density of the shadows. Although this information is not of very great importance it has however some value. It may though be extremely difficult to distinguish between certain eburnated sequestra which give very opaque shadows and metallic bodies. We shall refer later on to their differential diagnosis. But the information which the plate is able to supply to anyone who knows how to read it is not limited to these physical data. Omitting for the present the characteristics of radiological pathology inherent to each organ and which for certain viscera such as the lung would necessitate a complete monograph to describe them (we shall speak of the great importance of these later on when discussing the topography of projectiles) we obtain from the plate information of immediate and often vital interest to the surgeon: for instance whether the projectile under consideration is or is not within the bone. If it is necessary, for the purpose of being absolutely certain on the subject, to examine two plates taken at right angles to one another, it

FIG. 92.—Radiograph of the knee and of the upper third of the left leg seen from behind. The shadow of a German rifle bullet is seen in the shadow of the tibia and round it we notice a clear thin zone of about 1 mm. which follows its shape and seems to indicate the existence of an area of decalcification round the projectile. From this we may conclude with every probability, but not with certainty from a view of the plate, that the projectile is within the bone (verified by operation).

details to take in every case two radiographs in different directions, and as far as possible at right angles to one another or else stereoscopic plates. But as these radiographs give also important and sometimes sufficient information as to the depth of the projectiles, we shall refer to them again when we come to the chapter dealing with localisation; we shall therefore leave it for the present.

often happens that the examination of a single radiograph, if it is clear, can give information which is diagnostic.*

In fact there is generally produced round the projectile contained in the bone a zone of rarefying osteitis which is shown on the plate by a darker border (on the positive by a clearer border) which corresponds to the localised decalcification. Fig. 92 gives a good example of this.

But much importance should be attached to this appearance only if it is very clear because in certain cases, perhaps in consequence of the secondary radiation emitted by the metal, one can see a very slight halo round a shadow of a projectile not included in the bone, and this would easily lead to a mistake if we contented ourselves with this appearance unless it is very marked.†

Sometimes the aspect itself of the bony injury is sufficient as may be seen by an examination of Figs. 1 and 3 of Plate II.

Of not less importance is the study of the particulars in the vicinity such as cracks, fractures, splinters, deposits, sites of osteomyelitis, osteomata, pseudarthroses, etc., shown by the plate and which do not form part of this work (Plate III, Fig. 3, etc.).

A viewing box is of course a quite indispensable instrument for the study of all these details and we refer the reader to what has been said in the chapter "Apparatus" about the construction of a simple economical but perfectly satisfactory model (§ 15).

§ 24. **Fictitious Projectiles.**— If it is necessary to make a complete examination and to try as far as possible not to leave a foreign body undiscovered, it is perhaps of still more importance not to make the error of considering as projectiles shadows seen on the screen or plate, which are due to other causes. Contrary to what we may be led to believe at first if we have insufficient experience of the subject it is very easy to make such a mistake

* See the recent book by Barjon, *Examen radiologique du thorax* (Paris, Masson, 1916), in which the reader will find a lucid and authoritative statement on this interesting branch of medico-surgical radiology.

† The most conclusive proof will generally be supplied by a radiographic examination carried out by moving the limb under consideration and by making certain that the shadow of the projectile is included in the shadow of the bone.

especially with a screen examination if we do not possess the necessary anatomical and technical knowledge. In such cases we must not speak, as has been often done especially with regard to fractures, of errors of radiography. X-rays and the sensitive layer of the plate or of the screen obey only invariable physical laws and cannot "be mistaken," and it is only the human interpretation which is at fault if the radiologist is not sufficiently competent or, which is very often the case, especially now in view of the large number of radiographs taken by non-medical amateurs, when physicians and surgeons examine the plates by themselves and draw from them too hasty and faulty conclusions.

Screen images are simply projected shadows and the density of these shadows, which alone serve as a guide in our deductions as to the body which projects the shadow, is determined by two factors: the atomic weight and the mass of the body under consideration. It is therefore evident that there is a possibility of an infinite number of circumstances under which dissimilar bodies may give shadows of an equal density. It requires all the skill of an experienced radiologist who is perfectly well acquainted with and master of his technique and of the delicacy of interpretations to make a correct diagnosis by a series of rational deductions and by conclusions by analogy. This means that there is a great risk of frequent error. As they may lead to the most deplorable consequences by exposing a man to a serious operation which would be unnecessary and avoidable if proper precautions were taken, we think we are justified in explaining here rather fully all those errors the possibility of which has been shown to us by our own personal experience and by the experience of other people.

First of all we shall pass quickly over those errors which photographic imperfections may cause: defects in the emulsion, holes in the gelatine or partial melting when drying (often caused by microbic colonies), defects in the developing and fixing, and especially spots on the intensifying reinforcing screens, which are particularly important, especially in war time, in view of the almost constant and, to our mind, excessive use of these screens in most of the units which have only installations of a low capacity to reduce the time of exposure and to save the tubes.

It will be sufficient to recognise the spots on the screen used and their shape to avoid grave mistakes if it is not possible either to eliminate the spots or to replace the screens. A written interpretation of these marks made by the radiologist and signed by him will enable others to avoid them in the case of proofs which may have been examined by men in other units or during his absence (we refer to this later).

Shadows made by jewellery, buttons, pins, buckles of trousers or by any other bodies belonging to the clothing of the patients examined, or to their dressings (Michel's hooks, etc., not forgetting the bismuth spots on the shirt in examinations which necessitate the use of that substance) have frequently caused errors of diagnosis which a little care and the precaution of always removing the clothing as far as possible from the region to be examined would have prevented. But generally, even if there should be on the plate shadows thus produced, their regular and often characteristic form (for instance buttons with their two or four holes, etc.) should be sufficient to make them immediately recognisable.

We wish however to mention specially products of dressing of a high atomic weight and more particularly the iodised products, the first place amongst which must be given to iodoform, which may not only give shadows on the plates taken without removing the dressing (a very useful precaution whenever possible to do so without inconveniencing the patient) or without making sure of its composition, but may also adhere to the skin after the dressing has been removed and cause grave errors if no precautions are taken. Thus iodoform powder which remained on the skin has often given rise to a wrong diagnosis of "metallic dust persisting in the tissues."

These cases form a kind of transition between the causes of preceding errors which are purely extrinsic to the organism and the intrinsic causes. Heavy metalloids (iodine, etc.) or metals (zinc, iron, etc.) and their derivatives which are used for dressing, a complete list of which we cannot give here, may penetrate into jagged wounds and remain there, even after cicatrisation, imbedded in the tissues. In the latter case the differentiation from the metallic dust caused by the projectiles is sometimes im-

possible. The mistake would not be serious as it does not lead to operation. At the most it might have an effect on the mental state of the wounded if he were aware of the diagnosis. But in that case it is generally easy to alleviate his apprehensions by showing him the smallness of the particles.

If there are fistulous passages, care should be taken to ascertain that they do not contain iodoform gauze and that no iodoform or other substances or Beck's paste or any suspension of bismuth have been introduced.

It should not be forgotten that subcutaneous and especially intramuscular injections of medicaments of a high atomic weight such as mercury salts, iodised derivatives, etc., may cause opaque deposits which sometimes persist for many years, the aspect of which is fortunately in general sufficiently characteristic to draw one's attention to it.

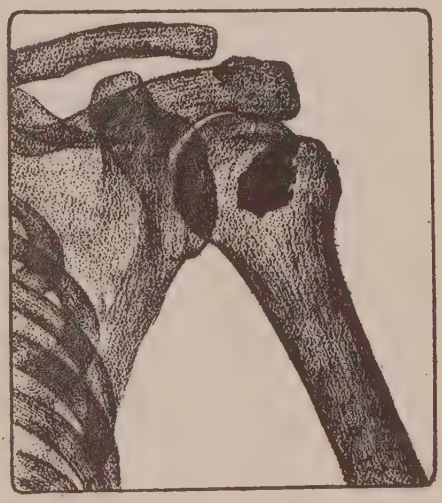


FIG. 93.—Radiograph of the right shoulder seen from the back. A very dense irregular shadow which closely resembles the shadow of a metal fragment is seen on the shadow of the humeral head. It is an iodoform dressing in the head of the humerus.

When dealing with the face we must always bear in mind stopped and crowned teeth and various other dental devices which in oblique view may produce metallic shadows giving rise to difficulties in diagnosis. We should also keep in mind opaque injections and dressings, without any apparent external wound, inserted through the mouth or nose into the normal cavities of the face.

But one of the most frequent causes of this kind of error and very often the most difficult to avoid in a rapid examination or when the observer is not very experienced is often

the result of "fillings" of bony cavities with iodoform so frequently inserted after scraping necessitated by osteo-myelitis. We show one of these "fillings," the regularity of its oval circumference will be noticed. However the diagnosis from a misshapen shrapnel bullet may be difficult should the patient say that he was struck by a shell which was not the case with this patient (Fig. 94).

FIG. 94.—Radiograph of the lower third of the right forearm seen from the front. In the loss of substance of the radius, in the shadow of a trail of an osseous proliferation there will be noticed two dark spots which may be taken for metallic fragments: they are two sequestra.

Besides intrinsic causes of error due to treatment, of which we have mentioned the principal ones without however exhausting the list, there are also metal bodies introduced into the organism by the surgeon for the purpose of prosthesis, such as trepanning plates, Lane's metal plates and Lambotte's metal plates, deep metal sutures in the bones or elsewhere, anastomotic buttons in gastro-intestinal surgery, etc., which we mention in passing.

Opaque foreign bodies in the alimentary tract: mercurial or iodised pills, powders or pastes composed of bismuth, fruit stones, as well as the remains of opaque lotions of bismuth or baryta, etc., may also be mentioned.

On the contrary pathological products of the body must be gone into more carefully.

At first we must mention abnormal bony growths which may lead to confusion and especially old and eburnated sequestra which become so opaque that it is very easy to take them even on excellent plates for metal fragments unless there is one of these fragments of sufficient size also present to show the difference in the density of their shadows. We have ourselves had occasion to extract rather large sequestra from the cranium and from other regions which had mostly been taken for projectiles and had been searched for without success

Next we may mention pathological concretions: calcul, of different kinds, from the salivary glands, gall bladderi kidney, ureters, bladder and prostate: the phleboliths, pelvic blotches, etc., are of little interest in this connection, but the concretions of bacillary origin and those due to atheroma are in practice sometimes of great importance.

M. Béclère has described formerly and all professional radiologists are now acquainted with those multiple calcified glands from whose presence a whole segment of a body may appear to be filled with projectiles. We know without laying stress on the fact that calcification is extremely common in lymphatic glands in many situations, but more especially in those groups which are clinically most frequently affected with tuberculosis. The opacity of the shadow produced is in direct proportion to the density of the calcareous deposit. Although a clinical examination of the neck and of the sub-maxillary region is generally sufficient to eliminate all chance of error, the same does not apply to deep groups of glands which are inaccessible to palpation such as those of the abdomen and especially of the thorax.

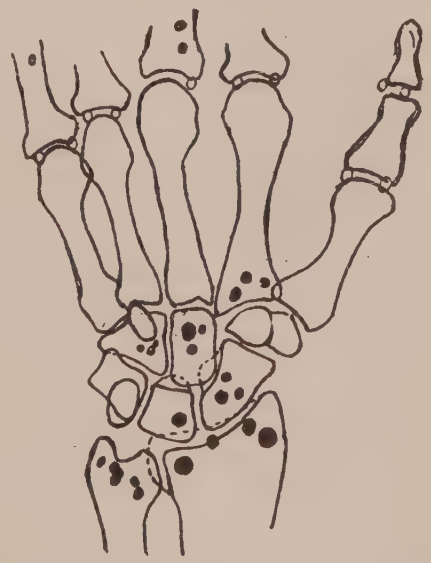


FIG. 95.—In this diagram we see various sesamoid bones as well as the commonest sites of condensation or rarefaction of bone.

There is no doubt that errors of diagnosis are most frequently made in the last-mentioned region, and that shadows due to organic calcification may easily be taken for metal fragments.

In the region of the lung, although this is the easiest organ to examine with the screen, there are many sources

of error, especially if the observer is not an experienced radiologist.

Taking into consideration the frequency of intrathoracic calcification even in relatively young patients in any given series of cases we are certain to find instances which will give rise to difficulties in diagnosis. As regards the lungs the great opacity of certain of these concretions seems to be considerably increased by the extreme transparency of the organ in which they are situated. By always obtaining a short history of his case from the patient we shall be able to avoid making a diagnosis that a projectile is present in the lung of a patient who has never been wounded—we have seen this mistake made—but if the patient has been wounded and especially if there is a thoracic wound present there may be a legitimate cause for doubt as to diagnosis, because the abnormal glands may take any shape or position, such as large and round single glands resembling a shrapnel bullet, small multiple shadows or a small isolated one (generally too round for a projectile and easier to recognise), and may be situated either in the lung tissue far away from the hilus or close to it in the mediastinum. Moreover, they may all show communicated pulsation. (See also Chapter II.)

The difficulty is still greater when we have to deal with calcareous plaques which are often found in the lung and in the pleura, and even in the pericardium. If they are taken on edge when they give a fairly dense shadow, they may easily be mistaken for a thin fragment of bullet casing. We are not at all ashamed of having extracted a calcareous plague from a man wounded by a shell on the same side of the thorax. The patient was suffering from hæmoptysis and complained of acute pain. In this case we had noticed before the operation the relatively slight opacity of the shadow of the projectile on the control plate which we always take in these cases.

The reader who wishes to know more about this interesting subject will study with advantage the excellent articles by Albert Weil whose beautiful plates published in the *Journal de Radiologie* (Volume I, 1914) show very clearly the typical aspect of these calcified glandular shadows. We shall however again refer to this in Chapter XI.

For particularly difficult or doubtful cases we recommend

that plates should be taken at different angles, and that a fragment of metal of about the same size as the suspected body should be fixed on the skin of the region examined. In screen examinations the same procedure should be adopted by comparing the shadow of the fragment of metal with that of the suspected body.

As regards plates they must of course be taken while the patient holds his breath, and when the shadow is pulsatile they must be instantaneous.

The same remarks naturally apply to atheromatic calcification of the aorta, but this occurs much less frequently. Not only abnormal or pathological shadows seen during a screen examination however may lead an inexperienced observer into errors of diagnosis. Shadows of normal bony structures may be equally misleading. In view of the importance and of the increasing development of this method of diagnosis and localisation we must insist on the commoner errors and point out to beginners in radiology the absolute necessity of a complete knowledge of osteology, not only of its normal appearances but also of its abnormal variations.

FIG. 96.—Radiograph of the left hand seen from its palmar aspect. The shadow of a piece of metal will be noticed superimposing the scaphoid. Three minute metal fragments are seen on the shadow of the os magnum, whilst the hook of the unciform and the pisiform give a much less dense shadow which could easily cause a mistake to be made if we had not the metal fragments present to compare it with.

Let us take the different regions of the body in order.

Skull.—It is easy to mistake various processes for metal fragments, but by changing the direction of the head the error can generally be avoided. A very dense mastoid may sometimes cause a novice to take it for a large metallic fragment.

In the *Neck* Chassaignac's tubercle and in the *Lumbar Vertebræ* the free end of a transverse process when its union with the process is not easily seen, which may often

be the case with a thin negative, may cause a second of hesitation.

Thorax.—During an examination in an oblique position the sternal end of the clavicle may be seen in the clear mediastinal space and may be mistaken for a shrapnel bullet if a control plate has not been taken. We have seen a similar case. In the upper limb the sesamoid bones of the hand (Fig. 95) have caused numerous errors of interpretation, and the hook of the unciform (Fig. 96) and sometimes the pisiform bone and in the head of the humerus the two tuberosities, which are very opaque to the rays, may cause confusion.

But one of the most frequent and real causes of error in the region of the shoulder is supplied by the coracoid process, which during an examination in a lying position is seen on the screen in the form of a simple round spot which has absolutely the same aspect and dimensions as a shrapnel bullet. In the case of a patient who had a shrapnel bullet in his right shoulder we have known a radiologist misled by a too hasty examination to suggest to the surgeon an operation on the left side on account of this appearance and we have several times seen this erroneous diagnosis made from the plates (Fig. 97).

FIG. 97.—Radiograph of the left shoulder seen from front. It will be noticed that the shadow of the free extremity of the caracoid process resembles a slightly deformed shrapnel bullet. The resemblance is still more perfect on the screen. This aspect is however much less accentuated if the shoulder is examined from the back (see Fig. 93).

In the lower limb the sesamoid of the knee is the most frequent source of error (Fig. 98), or an area of dense bone, situated underneath the cotyloid ridge giving the appearance of a small fragment of shell, and finally but less often the small trochanter has been taken for a shrapnel bullet.

As regards bony abnormalities (supernumerary bones of the carpus or of the tarsus, rare sesamoids, etc., areas of calcareous condensation in various bones and especially

in those of the carpus) we shall not dwell upon them here, and shall content ourselves by drawing general attention to them and warning the observer against these innumerable causes of error, especially novices and certain photographers who imagine that they are immediately able to interpret any screen or radiographic images without any anatomical knowledge and without any previous study.

§ 25. **Result of Examination : Written Interpretation.**—Let us suppose that we have avoided all these difficulties, and that our first examination, the object of which was simply to look for a foreign body, is terminated.

We have now obtained information as to the presence or absence of a projectile. In order to leave behind a proof of our examination so that the patient may benefit by it and to avoid a repetition which is useless and costly to the State (a matter of frequent occurrence), we must put down the result in writing and sign it, thus accepting the responsibility for the results given. This means that we must only state facts of which we are sure. We may write for instance: "No projectile visible from screen examination of the thorax" (if this is the region examined) but we must not say: "No projectile visible from screen examination" unless we have screened the patient's body, and still less: "There are no projectiles," a formula which is often used quite wrongly.

FIG. 98. – Radiograph of the right leg seen from inner side. The small oval shadow the size of a pea which we see behind the shadow of the femoral condyles corresponds with the sesamoid of the knee. Seen at the upper extremity of the interosseous space there is a shrapnel bullet which must however have come into contact with the bone to judge by the few metal particles which have become detached from it. (Compare also Figs. 1 and 2 of Plate I.)

If plates have been taken we must say: "No projectile visible from a screen examination of the thorax or on the plates taken," etc.

If our examination is positive we must supply particulars as exactly as possible of the dimensions and of the nature of the projectile. Dimensions indicated in millimeters are naturally the most precise and in general use. Nevertheless comparisons with the size of various seeds, fruits, etc., are currently used and on account of their simplicity may be employed. The millet seed, the grain of corn, the small pea, the haricot, the hazel nut and the filbert are considerably used in this kind of description (see next chapter).

Besides the information relating to the projectile itself it is of course necessary to give any additional details relating to the state of soft parts or bony structures shown by the X-ray examination. In Chapter III we have already insisted on these points, so we shall therefore only reproduce here as a specimen one of our reports (see Chapter IX).

Central Service of Radiology of the IXth district. Chef du Centre, M.A.M. 1st Cl., R. Ledoux-Lebard.	X-RAY REPORT	No. 2,693 Radiological Laboratory Place de Tours. Chef du Laboratoire, M.A.M. 1st Cl., Chabaueix.

Name and Christian name, V. Ernest. Corps, Xth Infantry.
Hospital 53. Physician or surgeon in attendance, Dr. Prouse.
Region examined: Finger joints of left hand.
Age 27 years.
Clinical diagnosis.
Date of the wound, September 8th, 1914.
Wound caused by bullet.
X-ray examination required for: Stiffness of joints of left hand, stiffness of the phalangeal joints.
N.B.—Care should be taken that patients sent for X-ray examination are quite clean.
(*To be filled by the attending physician.*)
(*This sheet must be attached to the official report of the wounded and never be communicated to him.*)
Examined October 1915.
Process utilised: Screen examination: Radiograph, No. 2,693.
Size, 13 × 18.

Injury found : Amputation of the middle finger. There is only a small portion of the base of the phalanx, ankylosis of the index.
Innumerable metal fragments scattered everywhere especially in the fingers, the largest of which is of the size of a grain of corn and is situated in the third interosseous space.

N.B.—Localisations will only be undertaken for patients belonging to units having a surgical department.

The information relating to the patient given in this report may appear rather complex, but it is absolutely necessary for a correct X-ray interpretation. In another chapter we shall see a copy of a report used in our district for giving the result of localisation.

We must also again point out here the advantage of not telling the patients the result of the examination and especially not letting them know that they have retained projectiles if it happens that they are not aware of the fact (this is however very rare now in spite of the very wise official instructions which have appeared on this subject in view of the number of X-ray examinations and of the frequency of localisation which naturally indicate the presence of a projectile).

To supply particulars as to the kind of projectile present we must first know the principal types now used in the armies, because some information of their nature may render great service to the radiologist by giving him exact details of the metal used and thus enabling the surgeon to use the right instruments. In the next chapter we shall deal with this subject.

CHAPTER VI

PROJECTILES AND THEIR EFFECTS

§ 26.—In the previous chapter we have given a general indication of the value of knowing, from a surgical standpoint, the characteristics of the projectile to be extracted. Thus to extract a French bullet from the depth of a wound we would not think of using a continuous magnet nor would we make use of an electro-vibrator in order to find a shrapnel bullet which being of lead would not vibrate. On the other hand we shall see in the following chapter how the determination of the depth of a projectile could be facilitated if we knew its exact dimensions. A knowledge of the real nature of a projectile, whether a bullet from a German or Austrian rifle, shrapnel bullet, fragment of a shell, etc., often gives us useful information by enabling us to know of what the projectile consists or what its dimensions are.

To this end and without desiring in any way to exaggerate the importance of these indications, which are often rendered deceptive by the change of shape of the projectiles or of their images, we think it advisable to pass here rapidly in review some elementary facts relating to the principal projectiles of the small arms and of the artillery used by the principal belligerent or neutral nations. We have taken them almost textually from the very remarkable and lucid works of MM. Nimier and Laval* the study of which we strongly recommend. We have completed them as regards the modifications in armaments which have taken place since their publication.

* Nimier and Laval, *Projectiles of War Arms; their Mutilating Action* (Paris, Alcan, 1899, one volume 16 mo); and by the same authors, *Explosives, Powders, Projectiles for Training. their Action and their Mutilating Effects* (Paris, Alcan, 1899, one volume 16 mo).

First of all let us point out in a general manner that all projectiles of firearms of the present day must be considered from the double standpoint of their mass and their velocity, as their mutilating power is measured by the product of one by the square of the other.* We draw a distinction between artillery or *large* projectiles and small-arm infantry or *small* projectiles.

I. Infantry Projectiles

§ 27.—Since their first appearance on the battlefields portable firearms have undergone many modifications

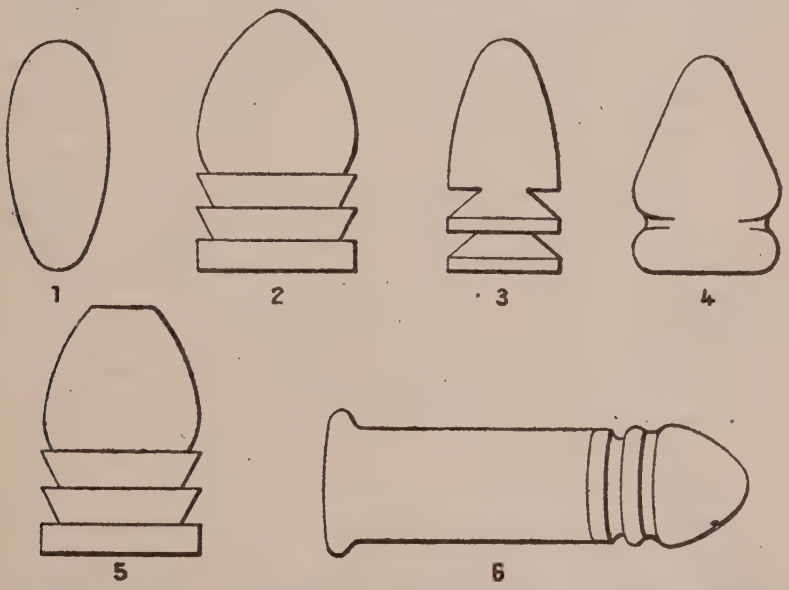


Fig. 99.—Some types of portable arm projectiles in use in the European armies from 1840 to 1886: (1) Minié rifle, France (1842); (2) Prussian needle rifle (1872); (3) Chassepot (France, 1866); (4) German rifle, 1871; (5) Martini-Henri rifle (England, 1871); (6) Gras rifle, model 1874.

and, from the surgical standpoint, their principal effects are:

(1) To reduce the mass of the projectile; (2) to in-

* The mutilating power depends for each projectile upon its actual force F which is measured by the half-product of the mass m by the square of the velocity v according to the formula $F = \frac{1}{2} mv^2$.

crease the actual force by which it is propelled. The rapidity of shooting of modern portable arms is also of some surgical interest. Brought to its maximum with the machine guns it has remarkably contributed to modify in the present war the number of wounded and especially their density in a given time if we may be allowed to use that expression.

Whilst the projectiles previous to 1886 (Lebel rifle) were of more or less different shapes the shapes of projectiles of the present time are almost identical. The former have only a retrospective interest for us and if we give in the enclosed figure the diagrams of some of these early forms it is only as a documentary evidence as the patients in whom the radiologist or the surgeon may still find them retained in the tissues are becoming very rare. Their principal characteristics are as follows :

Name of the Rifle.	Country and Date.	Calibre in mm.	Composition.	Weight in gr.
Minié rifle . . .	France, 1842	18·25	Soft lead	36
Needle rifle . . .	Prussia, 1872	15·43	—	21·5
Chassepot . . .	France, 1866	11	—	23
Infantry rifle . .	Germany, 1874	11	—	25
Martini-Henry rifle .	England, 1871	11·43	Lead 12 / Zinc 1	32
Gras rifle . . .	France, 1874	11	Lead	50

We shall deal more extensively with the modern projectiles. Their cylindrical body is terminated at their apex by a point and at the base by a circular flat or slightly excavated surface. Sometimes the point is truncated at the apex and thus represents a flat surface of about 1 mm. in diameter (S bullet or Italian bullet). The external surface, generally smooth, may present at its base a groove which corresponds to the impression produced by the neck of the cartridge. The calibres vary between 6 and 8 mm. and as a corrective for the reduction of the calibre ballistic requirements necessitated a prolongation of the projectiles which fact, from the surgical standpoint, constitutes a troublesome condition. This elongation which is particularly noticeable in our bullet

D compensates, at least partially, for the reduction of its calibre in relation to the mass of the projectile.

The length of a bullet is expressed in millimeters as well as in calibres, that is to say by the relation that exists between this length and the diameter of the cylindrical part or the calibre. Recent bullets measure in length on an average four times the calibre.

The weight of modern bullets is far less than that of their predecessors, but the main change that has taken place is due essentially to the construction of the case of the bullets. Most of them are formed of a core of hardened lead covered with a resisting metal envelope (the case), whence the name of cased bullets.*

As soon as the rifle is fired the projectile presents, besides the molecular vibrations by which its mass may be set in motion, three kinds of movements:

(*a*) *The Propulsive Movement* ordinarily called speed which varies according to whether it is considered when leaving the rifle (initial speed) or at a certain distance after having left it when it is modified by the resistance of the air and by the action of the weight (residual speed). It is the residual speed which alone is interesting from our standpoint and its study will enable us to foresee the differences which exist, all other conditions being equal, between the wounds under observation according to the distance at which they may have been produced.

(*b*) *The Rotatory Movement.*—Communicated to the projectile by the grooves to enable it to overcome the resistance of the air and to keep the pointed cylindrical bullet moving horizontally forward with its point in front. As this movement is practically constant it has no particular interest for us.

(*c*) *Abnormal Movements.*—As the centre of gravity does not coincide with the centre of the mass of the present very long bullets they have a tendency to pitch, to turn and to strike obstacles obliquely or crosswise. The same fact is also observed, to a higher degree, when the bullet even without being misshapen touches in its passage

* French bullets being all of solid copper are of course an exception; the new British bullet with an aluminium core, the details of which we have given in our tables, is the only one of its kind. See interesting booklet by Dutertre.

an obstacle or when it passes through a non-homogeneous body. A pirouetting movement is then produced which contributes especially with projectiles which ricochet to increase still further the extent of the point of impact. To obtain a clear idea as to the deformities produced by bullets in the tissues it is not sufficient to know their normal physical qualities; notice must be taken of the modifications which the latter undergo and especially of the modifications of form which cause such considerable differences in the transmission of the actual force of the projectile. The change of shape has the double effect of enlarging the striking surface and of increasing the time of its action by slowing down the course of the bullet.

In cased bullets the case lessens the change of shape of the core which is less resistant than the case; but if it gets torn it more or less opens and the lead of the core tends to escape. Wounded soldiers are often met with in whom the case of the bullet is found to be deformed and in the adjoining tissues are found up to a great distance series of lead fragments coming from the core. In all these cases the damage is generally very great and it is to produce the terrible effects caused to the human body by deformed projectiles that a systematic use has been made of specially prepared bullets (such as dum-dum bullets) which are intended to become deformed and produce "explosive effects" consisting mainly in extreme comminution of bones or in bursting of organs filled with liquids, or of real explosive projectiles that is to say containing an explosive charge which explodes at the moment when the projectile strikes a hard part of the body.* Without studying here the question of the relation existing between the distance at which a wound has been produced, the form and the nature of the projectile and the effects observed (interesting though it may be, and worthy of a detailed description), we simply wish to point out that it is necessary to be extremely reserved in the retrospective diagnosis of the projectile used even after a most complete X-ray examination before stating that a wound was caused by an explosive projectile. "Explosive effects" similar to those shown in published

* See the pamphlet by Dutertre on explosive projectiles (Paris, Maloine, 1916).

radiographs may perfectly well be noticed with ordinary projectiles, as has been demonstrated by experiments.

The radiograph reproduced on Plate II (Fig. 3) shows however a bullet of a special type which seems to have been fired base foremost in order to increase the surface struck and the wound produced.

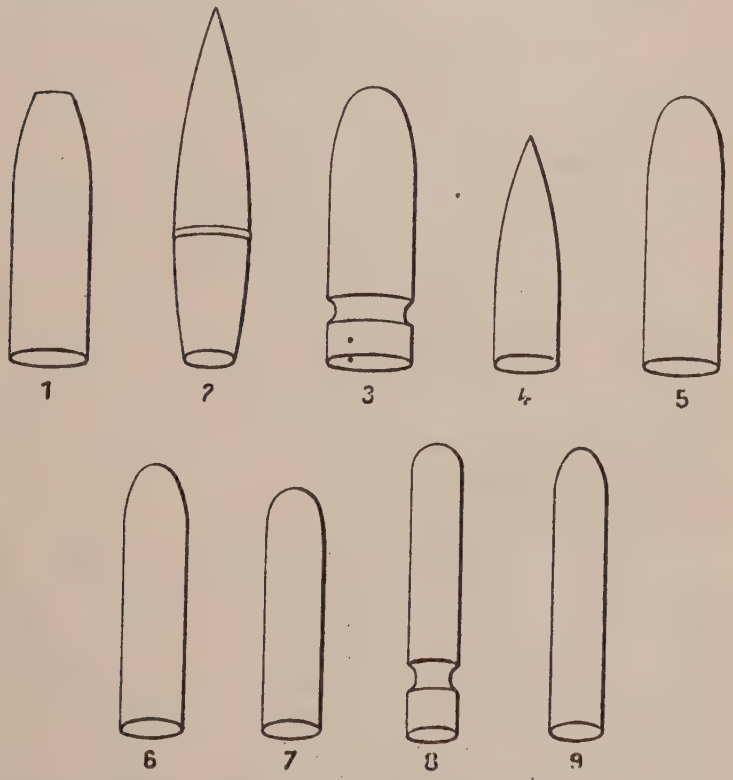


FIG. 100.—Projectiles of the principal rifles used by the allied armies: (1) France, S bullet; (2) France, D bullet; (3) England, rifle model, 1889–91; (4) Russia, rifle model, 1891; (5) Belgium, Mauser model, 1889; (6) Serbia, Mauser model, 1899; (7) Italy, Paravicino-Carcano, 1891; (8) Japan, Brisaka, 1905; (9) Portugal, Mauser, 1904.

We wish to point out that in general and with many reservations as to the correctness of these divisions the course traversed by small projectiles may be divided into three zones:

(1) *Zone of Typical Explosive Effects* when fired point-

blank but which are observed up to a distance of 300 meters and even more ;

(2) *The Perforation Zone* the dominant feature of which is a more or less clear perforation of the tissues. and which extends up to 2,000 meters and over ;

(3) *Contusion Zone* more or less over 2.200 meters.

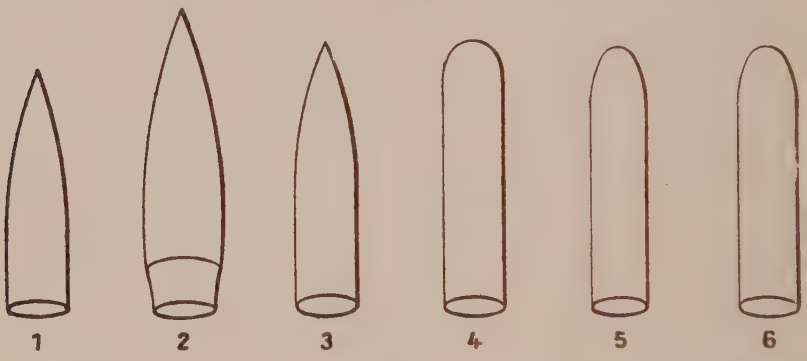


FIG. 101.—Principal projectiles used by the armies of some of the neutral countries: (1) United States of America (M. 1903); (2) Switzerland (M. 1903); (3) Spain, Mauser, 1893; (4) Greece, Männlicher-Schönauer, 1903; (5) Netherlands, Männlicher, 1893; (6) Roumania, Männlicher, 1893.

Although the number of those killed by small projectiles must be proportionately larger than before, the wounded on the other hand have more chances of recovery, and we have been able to notice the mildness of wounds caused by rifle bullets and the tolerance of the tissues of these foreign bodies which are often aseptic. These are points which should not be forgotten when arguing for or against the extraction of a projectile situated in a dangerous place.

The following tables sum up the characteristics of rifle bullets used by the principal belligerent or neutral powers, and supply particulars of their nature and dimensions which may be useful to radiologists and to surgeons in their daily work. It must however not be forgotten that armaments and munitions are being constantly modified in the course of the present war, and that moreover each belligerent often makes use of enemy material captured during the war.

Name of Country and Weapon.	Core.	Jacket.	Weight (in gr.)	Length (in mm.)	Diameter. (in mm.)
I.—ALLIED COUNTRIES					
FRANCE, Lebel 1886–1893, 8 mm., Bullet S.	Hardened lead	Nickelled copper	15·0	30·3	7·72
Bullet D (solid)	All copper	All copper	12·8	39·2	8·0
ENGLAND, Lee-Metford and Lee-Enfield, M. 1889–91, cal. 7·7 mm.	Lead with 5 per cent. antimony	Nickelled copper	14	31	7·87
BELGIUM, Mauser, M. 1889, cal. 7·65 mm.	Lead with 2 per cent. antimony	Nickelled copper	11	30	7·95
ITALY, Paravicino Carcano, M. 1891, cal. 6·5 mm.	Lead with 5 per cent. antimony	Nickelled copper	10·5	29	6·75
JAPAN, Arisaka, M. 1905, cal. 6·5 mm.	Soft lead	Nickelled copper	8	32·5	6·6
MONTENEGRO					
PORTUGAL, Mauser, M. 1904 cal. 6·5 mm.	Lead with 5 per cent. antimony	Nickelled copper	10·1	32	6·7
RUSSIA, Mossin, M. 1891, Bullet S., cal. 7·62 mm.	Lead with 2 per cent antimony	Cast steel covered with nickelled copper	9·0	25·5	7·85
SERBIA, Mauser, M. 1899, cal. 7 mm.	Lead with 2 per cent. antimony	Cast steel covered with nickelled copper	11·2	30·8	7·25
II.—PRINCIPAL NEUTRAL COUNTRIES					
UNITED STATES, M. 1903, cal. 7·62 mm.	Lead with 2 per cent. antimony	Cast steel covered with nickelled copper	9·7	27·8	7·85
DENMARK, Krag-Jörgensen, M. 1908, cal. 8 mm.	Soft lead	—	12·7	31·5	8·22
SPAIN, Mauser, M. 1893, Bullet S., cal. 7 mm.	Lead with 2 per cent. antimony	—	10	30·8	7·20
HOLLAND, Männlicher, M. 1893, cal. 6·5 mm.	Lead with 2 per cent. antimony	—	10·2	30·9	6·65
GREECE, Männlicher-Schönauer, M. 1903, cal. 6·4 mm.	Lead with 5 per cent. antimony	—	10·25	31·8	6·7
NORWAY, Krag-Jörgensen, M. 1896, cal. 6·5 mm.	Lead with 2 per cent. antimony	—	10·1	32·5	6·7
ROUMANIA, Männlicher, M. 1893, cal. 6·5 mm.	Lead with 5 per cent. antimony	—	10·25	31·8	5·65
SWEDEN, Mauser, M. 1896, cal. 6.5 mm.	Lead with 5 per cent. antimony	Nickelled copper	10·1	32	6·7
SWITZERLAND, Schmidt Rorbin, M. 1890–1903, cal. 7·5 mm.	Lead with 2·5 per cent. antimony	Cast steel and nickelled copper	11·3	34·3	7·82

† See p. 132, note 1,

Name of Country and Weapon.	Core.	Jacket.	Weight (in gr.)	Length (in mm.)	Diameter (in mm.)
		III.—ENEMY COUNTRIES			
GERMANY, M. 1888, Bullet S. cal. 7·9 mm.	Lead with 2·5 per cent. antimony	Cast steel and nickelled copper	10	28·0	8·22
AUSTRIA-HUNGARY, Männlicher, M. cal. 8 mm.	—	—	,,	,,	,,
BULGARIA, cal. 8 mm.	—	—	,,	,,	,,
TURKEY, Mauser, M. 1903, cal. 7·65 mm.	—	—	,,	27·5	7·92

The preceding considerations apply as a whole to the small projectiles of service revolvers and of automatic pistols all of which resemble rifle bullets more or less, but their diminution in size and speed in a general way reduces considerably the zone of explosive action.

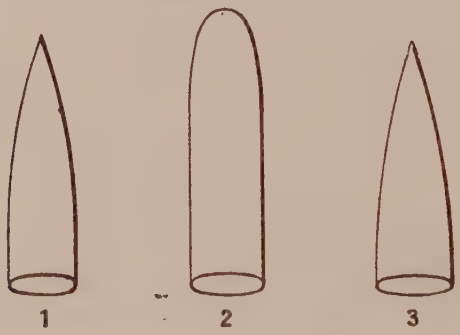


FIG. 102.—The principal rifle bullets used by the enemy armies. (1) German, 1888. (2) Austria-Hungary; Männlicher and also types of German bullets shown in the preceding number; Bulgaria, bullets of the two preceding types. (3) Turkey, Mauser, 1903 (also projectiles of the preceding types used of course with their respective rifles).

As regards projectiles of machine guns which are generally the same as those of rifles, the same ammunition being often used for either arm, there is no distinction whatever between them.

We shall not dwell upon projectiles for practising purposes, as they so rarely produce wounds that they do

not offer any practical interest, nor shall we describe projectiles of sporting ammunition or of portable arms for protection as their interest is of a very secondary nature at the present time, and the number of types is too large to enable us to supply precise and sufficiently complete information about them in the scope of this work.

II. Artillery Projectiles

§ 28.—Still more than the bullets large projectiles have become modified since their first appearance on the battlefield and we could not think of discussing all the old guns and their ammunition, the more so because the number of different types which have been in use is extremely large.

Even now the artillery consists of too many types and calibres for us to be able to describe them. Let us content ourselves by pointing out that under the general name of "gun" there are various types of artillery pieces which are still distinguished according to the trajectory habitually described by their projectiles, under the name of cannon, mortar, howitzer.

The cannon shoots, that is to say throws a projectile the trajectory of which describes a relatively moderate curve, the mortar bombards, that is to say throws by following a trajectory which to start with approaches the vertical a projectile intended to fall behind an obstacle, finally the howitzer shoots and bombards. These distinctions are however rather artificial and depend at present specially upon the gun carriage employed as may be gathered from the constant use during the present war of marine artillery for bombarding at long range.

As regards projectiles which alone interest us here directly it may be said, however paradoxical it may seem, that the more their volume has been increased the less they have acted as large projectiles. They may be distinguished as explosive shells and shrapnel shells and they often combine these two characteristics. But explosive effects do not enter into our subject and moreover they undergo fragmentation into small projectiles in both types.

We are thus dealing with a hollow metal mass of steel or cast iron of a pointed cylindrical shape with the point slightly flattened at the end, the base of which is provided

PLATE III

FIG. 1.—Radiograph of the right side of the head seen in profile. A rifle bullet of which only the base is missing casts its shadow in the light area of the maxillary sinus. (Teeth fillings should be noticed in this figure as they may be easily taken for projectiles.)

FIG. 2.—The same patient as in the preceding figure. Radiograph of the head, front view. The shadow of the projectile is still seen projected at the level of the right maxillary sinus, and it will be noted that the latter is very clearly less transparent than the left sinus, which is the result of the sinusitis caused by the projectile (verified by operation).

FIG. 3.—Radiograph of the right elbow seen in profile, extero-internal view. Notice should be taken of the periostitic changes and of the disappearance of the joint outlines which is due to the presence of the projectile (bullet encysted).

FIG. 4.—French bullet in contact with the sacrum on a level with the inlet (verified by operation).

N.B.—For the study of these various cases reference should be made to the particulars given in Chapters XI and XIV in which are included the various regions of the body, both from the point of view of the anatomical localisation of the projectile by the X-ray examination (Chapter II) and from the standpoint of the surgical extraction itself (Chapter XIV) undertaken by means of the intermittent control of the screen.

PLATE III

FIG. 1

FIG. 2

FIG. 3

FIG. 4

with a belt of lead or more generally of copper in order to ensure its fitting into the bore of the gun: the lower end is the base. This constitutes the shell. The truncated anterior part has an orifice in its centre called the eye into which is screwed the fuse, a mechanism by which the explosive charge contained in the interior of the shell. or the exploding powder the combustion of which will cause the projectile to burst, is fired, whilst the charging powder which is placed in the breech at the back of the shell either in a separate linen sack or connected with the shell like a real cartridge is intended solely for the propulsion of the projectile.

The fuse may either act on percussion, that is to say that it explodes from the shock when striking an obstacle. or after having been lighted at the start it detonates the exploding charge after a more or less long interval regulated at will by the gunner. Most of the fuses have a double effect, that is to say they have a percussion mechanism which comes into action in case the shell does not burst from the effect of the time fuse.

All these shells break up more or less irregularly; care has therefore to be taken to ensure that shells intended to reach combatants rather than to destroy their works should burst in a large number of fragments of such a shape that will not make them lose their speed in the air too rapidly and will allow them to retain a sufficient powerful force to kill or put out of action animals and men. Moreover the fragments must be spread over the required area in a suitable manner, that is to say within a certain radius round the bursting point. For this purpose shells have been produced which break up systematically and shells filled with bullets, generally called shrapnel from the name of Colonel Shrapnel who invented them. A shrapnel shell model 1891 of the French short 120 m. gun contains 630 lead bullets of a diameter of 12·8 mm. The bullets used are almost always of lead and spherical (sometimes but rarely polygonal), their weight varies between 8 and 15 grammes and their diameter is between 8 and 14 mm.

Finally, trench war has caused the return of trench engines, round shells and shells of various forms and especially of projectiles thrown by hand, namely grenades,

Consisting especially of a cast-iron case in the official types they may be atypical and improvised from receptacles of various forms and of different kinds (tins, etc.) and may contain all kinds of projectiles.

If we disregard whole pieces or almost whole pieces of a large projectile which are easily recognised such as fuses, bases, etc., which are very exceptional, we find in soldiers wounded by artillery fire either fragments of a shell of cast iron or more often of steel, the usual size of which will vary between a pea and a nut and whose irregular shape does not allow of any definite description or lead bullets either misshapen or not. There may also be found very rarely small fragments of copper coming from the belt and small pieces of aluminium from the fuse.

As regards the nature of the foreign bodies found from grenades and trench engines they generally consist of fragments of cast iron or of steel, but all sorts of material may be discovered. The radiograph reproduced on Plate I (Fig. 3) shows fragments of wire, part of the binding wire of such a missile. Finally trench weapons have altered our radiological ideas by making more and more frequent the enormous number of minute projectiles and even trails of metallic powder. With regard to the size of projectiles found in the wounded we can classify them as follows:

(1) *Dust.*—Metal fragments up to 1 mm. in diameter (Fig. 3, Plate VIII).

(2) *Minute Projectiles.*—Small pieces up to 4 mm. in their longest diameter (smaller than a grain of corn according to the current terminology); (Fig. 4, Plate VIII).

(3) *Small Projectiles.*—Fragments between 4 mm. and 1 cm. in diameter (from the size of a grain of corn to that of a large pea); (Fig. 4, Plate VIII).

(4) *Medium-sized Projectiles.*—Between 15 mm. and 2 cm. in diameter (from the size of a large pea up to a large haricot); (Fig. 96 and Fig. 4, Plate VI).

(5) *Large Projectiles.*—Various bullets and fragments the longest diameter of which is over 2 cm. (over the volume of a haricot); (Fig. 6, Plate III).

Although this distinction is artificial it has nevertheless a certain practical interest both from the X-ray and surgical standpoint.

It is evident that the projectiles of the first category cannot be removed. The utmost that could be done would be to take out the whole area of tissue containing a well-localised trail of metallic dust. The projectiles of the second category could only be extracted in quite exceptional cases, and then only with the control of the screen provided it has been possible to mark them, as the tactile sensation given them to the surgeon is often not sufficient to ensure their extraction, even with the most exact marking and with an irreproachable compass localisation. If it is therefore decided to operate absolutely definite indication for operation and appropriate technique are essential. The three last categories alone may be considered as really "surgical." We shall later on discuss this subject further.

As regards the "shape" of the projectiles it is evident that more or less irregular and rough fragments are generally much less tolerated by the tissues, even if they are of a smaller size than smooth projectiles such as "bullets"; it will also be evident that they are more frequently the cause of infection and of early or late septic accidents, owing to latent microbic infection, and that they are as a rule surrounded by dense tissues and are therefore the cause of considerable inconvenience from the purely mechanical standpoint which may call for their extraction These few points, which we are only able to touch on in passing, will also have to be carefully considered when the question arises of operative interference We shall not consider here the explosive effects of projectiles or of "indirect" projectiles, and we shall content ourselves by giving a few figures which illustrate sufficiently those various points (see plates not included in the text).

CHAPTER VII

GENERAL THEORY OF METHODS OF LOCALISATION

(Written in collaboration with Mr. A. Dauvillier)

§ 29.—Before going into the physical problem of the localisation of foreign bodies we must remember the very simple law on which all the methods are based.

We have already seen that if we consider a tube in action X-rays are given off near the centre of the anticathode and from a surface which is always small enough to be regarded as a single point for emission of rays.

We have thus a source of X-rays which is practically a point and may be compared to an intense and single source of light which throws a clear sharp shadow of surrounding objects.

Geometrically a focus like this is a centre of conical projections (see Chapter III). Supposing C to be that centre and CX the axis along which the source of rays travels perpendicular to a linear object AB which is opaque to the radiation of C. A surface P being a screen at right angles to CX will act as a plane of projection and we shall perceive on that plane the magnified image $A'B'$ of AB (Fig. 103).

The triangles CAB, $CA'B'$ are then similar (Fig. 103) because they have a common vertical angle, and the bases AB, $A'B'$ are parallel by definition as being two perpendiculars to the axis. Their sides are therefore proportional and we may write:

$$\frac{AB}{CO} = \frac{A'B'}{CO'} \qquad (1)$$

that is to say, as we have previously seen (see Chapter III), the size of the shadow as projected on the screen is in direct proportion to the dimensions of the object and the distance

which separates the surface P from the source C and is inversely proportional to the distance of the object AB from the source.

This consideration enables one to form some deductions which are often useful in the radioscopic examination of foreign bodies.

In practice the distance CO' of the anticathode to the fluorescent screen P may often remain invariable say for examination of the pelvis or thorax. A shrapnel or rifle bullet, the dimensions of which are known to us beforehand, will produce a shadow which will be the larger the deeper

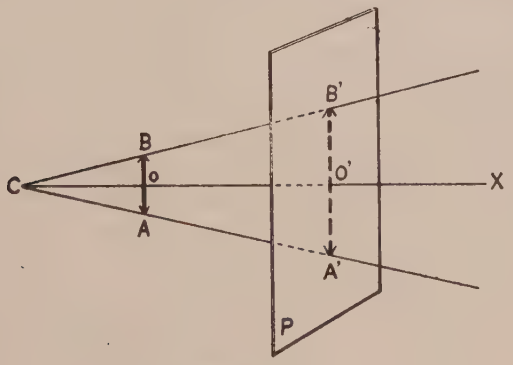


FIG. 103.

its situation (that is to say nearer to the anticathode than the screen). Two examinations one from the back and the other from the front—(the distance from the scree ı being constant)—will thus supply two shadows of identical dimensions if the foreign body is median, but different dimensions if it is nearer the one than the other, because the smaller shadow will evidently be obtained from the side to which it is nearer. Although this is rather a rough localisation nevertheless it renders in the course of our daily examinations important help by giving immediately an approximate idea of the depth of a projectile and especially in enabling us to choose the method by which a more exact localisation may be undertaken.

Provided we have this method already indicated most proceedings must, and in fact do, rest on the theory of geometrical triangulations.

Let us however point out that the fundamental equation indicated in the preceding page could not be used to determine the situation of a foreign body of an unknown size—which most frequently occurs—because then we can only carry out two direct measurements: one of the distance from the anticathode to the screen CO' and two of the size of the projected shadow (radioscopic or radiographic) $A'B'$—thus we are in the presence of a single equation with two unknown quantities, that is to say of an insoluble problem (but in the case of a shrapnel bullet for instance, the diameter of which is known, we can immediately obtain the result desired).

Therefore the method to be used requires either two sources of X-rays working simultaneously or—and this is the most frequent—the displacement of a single source from one distinct position to another, or else a displacement of AB, that is to say a displacement of the object containing the foreign body. These two manipulations will then supply two distinct sets of data which can be expressed in two equations and we thus come back to a problem which is easily solved.

Most of the methods of localisation proposed since the discovery of Röntgen did not include even elementary mathematical considerations. The authors seemed especially to be endeavouring to realise the seat of the foreign body as a material representation in space. Most of these proceedings originated from the following considerations:

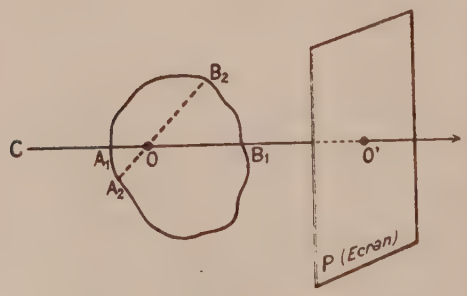


Fig. 104.

Suppose C to be the point of emission of rays, O the foreign body and O' its shadow thrown on the surface P of the screen (Fig. 104), and let the point of entrance and exit of the normal ray on the surface P be A_1 and B_1, then let us mark those points on the skin by placing in front of and behind the subject and at the proper level an opaque pointed rod and marking thereupon the

points of contact with a skin pencil. Let us then proceed to do a second similar operation, after having turned our subject through a certain angle, or after having displaced the source of rays some distance, and we shall then obtain two other points A_2 and B_2. The four points A_1, B_1, A_2, B_2, are such that straight lines joining each pair must cross in the foreign body.

Authors have constructed graphically the quadrilateral figure A_1, B_1, A_2, B_2 (by taking with the aid of compasses the distances A_1, B_2, B_2, B_1 etc.) or have materialised the curvilinear outline of the foreign body by plotting out the four points. All these proceedings are easily accomplished without any special apparatus and constitute the total of what is called the haphazard method (*le procédé de fortune*).

Another more recent group of proceedings consists in marking on the screen itself and not on the body the position of the shadows for two successive positions of the tube. Only the point of emergence of the normal ray is marked on the skin.

These proceedings are based on the following theory: Supposing C and C' to be two successive positions of the point of emission and O the foreign body and O_1 and O_2 its shadows (which correspond to the positions C and C') and supposing the screen to be at right angles to one of the axes of projection (since this axis CO_1 is the normal ray) and the displacement CC' to have taken place parallel to the surface of the screen, then the two triangles $CC'O$ and $OO_1\ O_2$ are similar and their sides proportional (Fig. 105).

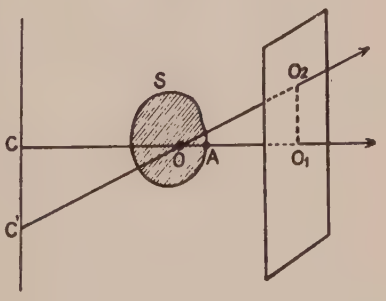


FIG. 105.

We can thus write:

$$\frac{CO}{CC'} = \frac{OO_1}{O_1O_2} \qquad (2)$$

OO_1 being the distance of the foreign body from the surface of the screen.

This equation cannot be solved directly because it contains a quantity of CO which we cannot measure and which we must therefore eliminate. Let us point out however that we can write :

$$CO = CO_1 - OO_1$$

but we can measure directly CO_1 which is the distance of the anticathode of the tube to the screen and OO_1 is but the distance from the screen to the foreign body of which it will suffice to cut off the distance from the screen to the skin, namely AO_1, which is directly measurable, in order to obtain the required unknown OA which is depth of the foreign body. We obtain thus :

$$\frac{CO_1 - OO_1}{CC'} = \frac{OO_1}{O_1O_2}$$

We thus obtain a first degree equation with one unknown OO_1, all other quantities (that is to say CC' the displacement of the tube—and O_1O_2 the displacement of the shadow) being measurable we obtain finally :

$$(CO_1 - OO_1) \times O_1O_2 = OO_1 \times CC'$$

or by developing :

$$CO_1 \times O_1O_2 - OO_1 \times O_1O_2 = OO_1 \times CC'$$

which may be expressed in the form :

$$CO_1 \times C_1O_2 = (OO_1 \times CC') + (OO_1 \times O_1O_2)$$

that is to say :

$$CO_1 \times O_1O_2 = OO_1 \times (CC' + O_1O_2)$$

or :

$$OO_1 = \frac{CO_1 \times O_1O_2}{CC' + O_1O_2} \qquad (3)$$

Finally by measuring the distance AO_1 which separates the skin from the screen we obtain the depth OA.

$$OA = \frac{CO_1 \times O_1O_2}{CC' + O_1O_2} - AO_1$$

If we designate by h the distance from the anticathode to the screen CO and by d the displacement of the tube CC' and by a the displacement of the shadow of the foreign body on the screen O_1O_2 and finally by x the distance OO_1 then our equation (3) may be written :

$$x = \frac{h\,x\,a}{d+a} = \frac{a}{d+a}\,x\,h \qquad (4)$$

which is a general formula and can easily be remembered.

But that formula may be considerably simplified. In practice the displacement CC' is a constant of approximately 10 cm. If we maintain the distance from anticathode to screen constant, the equation shows that the distance OO_1 is only the expression of a single variable quantity, namely the displacement O_1O_2. It is therefore possible to trace on the screen a scale which will give by direct reading the distance OO_1 ; there will only be one measurement to make that of the distance AO_1.

If for technical reasons we wish to leave the distance from anticathode to screen CO_1 variable it is possible to simplify the equation (3) by reducing it to two factors CO_1, and $\frac{O_1O_2}{CC' + O_1O_2}$; as the second one depends only on O_1O_2 , it is also possible to trace on the screen a scale graduated in coefficients :

$$\left(\frac{O_1O_2}{CC' + O_1O_2}\right) \text{ or } \frac{a}{a+d}$$

Finally it is also possible to avoid all calculations by using in the latter case a ready-reckoner, or by solving the triangulation by means of rules and a wire. A trigonometric solution of that problem has also been given.

The triangle OO_1O_2 being a rectangle (Fig. 105) supplies the solution :

$$OO_1 = O_1O_2 \; tg. \; (OO_2O_1)$$

It is then sufficient to measure O_1O_2 and so obtain directly the reading $tg.\,(OO_2O_1)$ in order to get the resolution. Another series of solutions is given by varying the distance CC' in order to construct particular triangles.

Thus by causing a displacement CC' so that the angle

$CC'O$ is equal to 45° then its opposite alternating angle OO_2O_1 is also of the same value. The triangle OO_2O_1 is then known and O_1O_2 gives by preliminary graduation the quantity OO_1.

Similarly by making isosceles the triangles $CC'O$ and OO_2O_1 so as to have :

$$\widehat{CC'O} = \widehat{COC'}$$

and :

$$\widehat{O_1O_2O} = \widehat{O_1OO_2}$$

the distance OO_1 becomes equal to O_1O_2, and we have by direct reading the solution we desire.

All these proceedings lead to the same aim with extremely variable degrees of precision. As soon as the material realisation of the triangulation in the space has been effected, the accuracy of the result depends only on the skill of the operator and on the care with which he takes his measurements, and a series of successive determinations alone can indicate the approximation obtained. Should we, on the contrary, start from equation (3) or (4) we can calculate by means of certain experimental data the degree of precision which may be obtained. As an experiment we shall make a calculation by the methods which rest on equation (3).

We have seen that the depth of a point of the foreign body has been given by the relation :

$$OA = \frac{CO_1 \times O_1O_2}{CC' + O_1O_2} - AO_1$$

Let us suppose that the correction AO_1 may be measured * with every desirable accuracy which is more or less the case in practice, and that consequently its measurement contains only a negligible mistake.

There remains therefore the term :

$$OO_1 = \frac{CO_1 \times O_1O_2}{CC' + O_1O_2}$$

The differential logarithm of this expression gives the

* In practice we should always endeavour to reduce to a minimum the quantity AO_1 which should never be bigger than the quantity AO to be measured.

utmost limit of the mistake which may be made in the result, in the light of possible partial mistakes.

$$\frac{\delta(OO_1)}{OO_1} = \frac{\delta(CO_1)}{(CO_1)} + \frac{\delta\left(\frac{O_1O_2}{CC' + O_1O_2}\right)}{\frac{O_1O_2}{CC' + O_1O_2}}$$

The order of the dimension of the distance anticathode to screen being generally 50 cm. the relative mistake which is habitually made on that measurement is about $\frac{1}{100}$ because it is difficult to appreciate without special apparatus the exact position of the focus on the anticathode. This mistake is therefore not important.

Similarly the mistake made on the displacement (generally automatic) of the tube is slight. On a displacement of 10 cm. a mistake of 1 mm. can be made at the utmost, and we can suppose it to be less.

On the contrary, it is difficult (especially in radioscopy and without special devices) to appreciate with some exactness the distance of two homologous points of two projected shadows. Thus on a value of O_1O_2 approaching 1 cm. experience shows that in a large number of radioscopic cases it is possible to make on this length a mistake approaching 2 or 3 mm. Let us suppose it to be at least 2 mm ; we shall have :

$$\frac{\delta(OO_1)}{OO_1} = \frac{1}{100} + \frac{\frac{10}{110} - \frac{8}{107}}{\frac{10}{110}} = \frac{1}{100} + \frac{17{\cdot}8}{100} = 18{\cdot}8 \text{ per cent.}$$

Thus in this very plausible case which is often met with in practice the result will be tainted by an error reaching almost 20 per cent.

Sometimes the objection is made that accuracy is superfluous in a matter of localisation, and that it is sufficient to indicate the depth up to within 1 cm. in order to satisfy the utmost requirements. In fact, the human body is not the stable solid which theory supposes it to be, and sometimes soft parts render accuracy illusory : we must not therefore expect to obtain the exact measurement. However in the example which we have just considered the depth of the foreign body, supposing that the screen

touched the skin, was $500 \times \frac{1}{11}$ or 45 mm.; an error of 20 per cent.—this corresponded therefore to 9 mm. more or less, that is to say that the result given could vary between 36 and 54 mm.

Nobody will consider this approximation sufficient, especially in the case when the projectile is situated in the scapular region or in the pelvis. The absolute outside error should in reality not be more than 5 mm., it is therefore necessary to indicate the depths to an average of about 5 per cent.

But there is another cause of error which theory cannot analyse and which seems to have always been neglected. The theory which we have explained here applies to material points such as the point of a bullet or a sufficiently small isolated piece of metal. In those cases where the foreign body is an unaltered shrapnel bullet the preceding equations apply to the centre of the spherical bullet and are correct; but war projectiles have all possible forms and very often most complicated shapes. In the case when we localise a fragment having the form of a piece of wire or of a leaf, it is impossible to recognise two homologous points in the very different shadows projected on the screen—moreover the two projections are not alike.

It is for all these reasons that the physical problem of localisation should only be looked upon with circumspection, and it must be completed by the utmost possible number of physiological considerations and examinations in various positions.

CHAPTER VIII

LOCALISATION OF PROJECTILES

§ 30. **General Considerations : Historical Survey.**—Let us suppose that we are dealing with a patient in whom a preliminary examination has revealed the existence of a projectile. The clinical indications seem to indicate removal. Before making a definite decision unless such is indicated in advance by urgent necessity, the surgeon must be informed exactly as to the depth of the projectile under the skin.

We can tell him in most cases, after a well-conducted radioscopic examination, whether the projectile is lodged nearer to the anterior surface or to the posterior, and whether it is intra-osseous or in the soft parts, and in which organ and in which group of muscles it is situated (see Chapter XI) or whether it does or does not move on palpation, and in this case which is the point on the skin at the level of which the maximum movement may be determined. All this information, which we must never omit to supply if we can, and we can do it more often than is generally thought, would by itself enable the surgeon to undertake the extraction in a large number of cases. But even if he dispenses with the screen control it does not exclude (especially in the case of old wounds) lengthy groping about, and if the operator has not this facility, the number of setbacks under these conditions may be relatively high, or else the damage produced may be too considerable. He requires more information. We must give him more precise information as to the depth of the projectile under the skin at the point chosen for the incision.

How are we going to proceed in practice to determine that distance and utilise the general theoretical ideas indicated in the preceding chapter ?

It is not methods of procedure that we shall lack, but the reverse. Since the beginning of the war we have seen the appearance of such a large number of publications describing the methods of localisation that we should be quite embarrassed which method to choose if we were to master each, as our available time would not suffice for such work.

But all these methods are mostly personal variations, very often almost insignificant, of two large methods of procedure, *i.e.* either on the one hand localisations which follow two intersecting axes, or on the other the determination of the depth by estimating the distance of the two shadows of the foreign body produced by a displacement of the tube. These two common methods, the general theory of which we have given in the preceding chapter, have been known and applied almost from the beginning of radiology. By this we mean to say that many amongst the recent publications have only republished, under different names, old and perfectly well-known procedures. These regrettable errors are due to a large extent to the number of radiologists who have suddenly sprung up since the war, and who, without any previous knowledge, thought in good faith they had "discovered" what every professional radiologist has known for a long time. It must however be stated in their favour that the extreme difficulties under existing circumstances which surround bibliographical research partly excuse their ignorance. The same reason makes it impossible for us to give here a complete historical description of this interesting question and forces us to limit ourselves to a short summary.

Finally it must be acknowledged and emphasised that although the theory had been known for a long time and, especially owing to Haret and Hirtz, practical applications have been able to be undertaken, it is nevertheless indisputable that this war, by enabling all radiologists to study an extraordinary number of cases and by imposing upon them the necessity for rapid and suitable solutions, has absolutely transformed the question of localising projectiles and has enabled extraordinary progress to be achieved Almost every radiologist, whatever the particular method which he has adopted for his personal practice, is to-day a perfect master of this question, and in this respect the

war will have brought about, if not a great advance in our theoretical knowledge, at least a considerable extension of the practical applications of it.

Historical.—X-rays were discovered in December 1895, and were immediately applied to the search and then to the localisation of projectiles. In March 1896 Buguet and Gascard explained the technique of the first real method. In June of the same year Brissaud and Londe applied the taking of two plates at right angles to the search for an intracranial projectile, an idea which was later on taken up by Mignon. But as errors were frequent mostly because of the difficulties in technique, and because of insufficient understanding of the problem, localisations were only approximate.

In March 1897 Rémy and Contremoulins inaugurated in France the era of instrumental methods, and the latter of these two authors commenced the study of his compass.

In August of the same year Leduc published a work of *The Rapid and Precise Determination of the Position of Bodies seen in the Tissues by means of Radioscopy*, and thus marked the beginning of radioscopic localisations.

In England Mackenzie-Davidson and Hedley started studying in January 1897 and presented in 1898 the first model of their cross-thread localiser, which became classical in the United Kingdom and served as the point of departure for numerous imitations. In 1899 Massiot invented his compass. Guilloz, Londe, Mergier, etc. indicated new methods of technique, and since then publications increased from year to year.

We shall only mention, as deserving special attention, the works of Aubourg, Béclère, Belot, Delherm, Guilleminot, Laquerrière, Albert-Weil, the important publications of Haret and of Tuffier and their methods of localisation for the cranium and finally the multiplication, in the years preceding the war, of compass methods of Miramond, of Laroquette and especially of Hirtz, and the original works of Mazérès.

§ 31. **Radioscopy and Radiography.**—Since the war, as we mentioned before, the number of publications devoted to the localisation of projectiles by means of X-rays has been considerable. But although at the beginning there were hardly any professional radiologists in the armies

who together with Haret dared to raise their voices in favour of radioscopic methods (which were defended at the base by the authority of M. Béclère) we have seen gradually a complete change of opinion taking place, as practice showed the necessity of working quickly and the possibility of working well with the screen, and many of those who were the most ardent defenders of exclusive radiography have since adapted their proceedings to radioscopy which continues to gain ground every day.

Without wishing to establish parallels between two methods which, as we have already mentioned (§ 11), must always go together and mutually complete and not exclude each other, we shall only point out that the objections raised against radioscopy may be summed up under four principal headings :

(1) Insufficient accuracy of localisation ; (2) impossibility of seeing on the screen certain foreign bodies ; (3) Absence of an impartial and permanent record ; (4) dangers to the operator.

As regards the latter objection we refer the reader to Chapter IV and, especially, to § 17, as also to the developments given in Chapter XIII. From these it will be seen sufficiently well that with modern materials giving real protection (opaque shield, radiological table protected laterally by opaque screens, opaque gloves and glasses, an opaque and properly movable diaphragm), the dangers which threaten the radiologist during radioscopic localisations are not greater and are rather less than those to which he is exposed during visceral examinations (thorax, stomach, etc.), and no specialist would renounce this. We say that the dangers are less, because the localisations are made especially in recumbent positions in which the path of the rays issuing from the diaphragm rises vertically in front of the observer instead of striking him directly as in upright examinations.

Thus without wishing to consider the danger as absolutely nil we think it must not be exaggerated, because a careful and well-equipped observer is only exposed directly to the action of secondary rays, which is a very small matter in spite of what certain authors may have said.

As regards the accuracy of radioscopic methods, data will be found in the pages of this and of the following

chapter, and it will be possible to conclude that, although theoretically certain radiographic proceedings such as the Hirtz compass seem to be capable of a great and almost absolute exactness, nevertheless the human body, not being an unchangeable geometrical solid fixed in an invariable position, leads to the result that there is in practice no difference between these and certain radioscopic proceedings which enable localisations to be made within an error of from 1 to 2 millimeters.

As regards radioscopic visibility, we have examined it sufficiently in detail in § 18, and need not refer to it again, except to remind the reader of our conclusion that with a good technique every projectile which can be removed surgically is visible on the screen and may be localised radioscopically.

Finally, as regards the absence of a permanent record, this is a criticism which may be addressed to those—and we are not of their number—who do not, in every doubtful or difficult case, complete their radioscopic examination by a plate (see what we say in this respect in § 35). Besides, in the question of war projectiles it is not only absolute precision and accuracy which count, as certain authors seem to think. Convenience, rapidity and economy are also very important factors and entirely in favour of radioscopy.

Moreover, we must also take into account the conditions under which the examination is carried out, and at the front within the scope of action of X-ray cars only can radioscopic localisation be carried out in a systematic and regular manner.

Finally—and we shall refer to it again (Chapters XII and XIII)—methods which may be sufficient for recent projectiles, when the wounds are still open, will not be sufficient for old projectiles which have become embedded for some time in healed tissues.

We could not think of describing here, even in an abbreviated manner, all the methods of localisation relatively old, or published since the war, because to do this we should have to double the extent of this work without improving it greatly, as many of these methods only represent insignificant variations of technique. We prefer to describe in a general manner the method of X-ray

examinations, and to choose, for purposes of detail, some typical proceedings which appear to us particularly favourable owing to their suitability, exactitude, rapidity or as presenting an interest on account of their originality.

We strongly advise those who start practising X-ray localisation to choose above all a rapid, convenient method with special attention to its general application, and which can be carried out without requiring too complicated apparatus, or at least with a special portable arrangement which could easily be adapted to all current types of apparatus.

By this we wish to say, first of all, that in a general way we advocate radioscopic methods. It must never be forgotten that surgical extraction is as a rule the ultimate motive and the principal aim of localisation which must always be carried out in the operative position, if we wish to avoid frequent and fatal mistakes, due to the change of situation of the projectile on change of position of the patient. This is the reason why methods such as that of Menuet lose part of their value. It also implies the necessity, if we wish to perform perfectly satisfactory work, of constant collaboration between the surgeon and the radiologist and shows us again that it is necessary for the latter to possess a good solid medico-surgical education.

§ 32. Localisation of a Projectile by the Dimensions of its Shadow.—We just wish to remind the reader that it is possible to calculate the depth of a projectile, of which we know the true dimensions, according to the magnification of the shadow, which may be easily measured either on the screen or on the plate.

This is a method rarely used, because rifle bullets and shrapnel bullets are projectiles, which more and more constitute a minority of the projectiles to be localised. However, for these projectiles, if they are whole and not deformed, it is in fact possible to calculate quickly the depth either by referring to various tables of magnification or by means of a series of radiographs of the projectile taken in advance and placed at known distances, as has been done for instance quite recently by Pirie (*Arch. of Radiol.*, October 1916, p. 138).

For a shrapnel bullet, which is spherical, the position in

space is unimportant. For rifle bullets it must be taken into consideration that only their transverse diameter remains unmodified and may serve as a guide. As regards this we refer the reader to the data given in the tables of Chapter VI for rifle bullets, but we wish to point out that for shrapnel bullets the diameters are sufficiently variable as to render this method, which is so inaccurate and so little to be recommended in a general way, of still less value.

§ 33. **Localisations according to Intersecting Axes.**— We have already seen several times (§ 13 and § 21) how it is possible to find out the situation of a projectile or of some body opaque to X-rays by means of two images taken at right angles to each other, that is to say by means of two examinations, one from the front and the other from the side. But in order that the axes may be quite perpendicular and in order to avoid causes of error, the patient must be fixed and the tube and plate displaced by 90° which is a relatively long distance and sometimes not quite convenient. Moreover, we have no indication yet as to the position of the projectile with reference to the skin, which is a matter of capital importance to the surgeon (the method which consists in making use of two different tubes is not of any greater advantage). In order to succeed we must note the position of the normal ray as seen in each of the two directions and mark on the skin the points of entry and of exit. The marked points obviously give the approximate direction of the projectiles situated at the point of intersection of the two rays.

It is this very simple general method which served as the basis for numerous different technical proceedings pompously called methods, which very often only differ from each other as regards minor considerations in the way of aiming at the projectile or of marking the points on the skin.

The initial proceeding already described, which consists in indicating the points with an opaque rod left in place until a mark with a pencil * is made on the skin, may be replaced by more rapid, elegant, or more precise methods.

* For a better way of marking the skin see what we have said in Chapter IV, § 16.

The Forceps Method.—Dr. J. Belot* has used, since the beginning of the war, a method which he has named the "forceps method," the originality of which consists in using a pair of forceps with rings at the ends, whence its name. The forceps are similar to those which are used for taking out plates from reducing baths: the flat ends have been replaced by two metal rings situated opposite each other perpendicularly to the plane of the arms of the forceps. By pressing on the handle of the forceps the arms are opened; on relaxing the hold the arms spring together again. It is thus easy to take hold of a portion of the body between the arms of the pincers and to keep it in place, because the two arms tend by themselves to press the body which they seize. The maximum width of the arms must be sufficient for a thigh. In practice Dr. Belot prefers to have two models: one, easy to handle, is used for arms and legs; the other, being larger, is used for the thighs, for the shoulders and the trunk (Figs. 106 and 107).

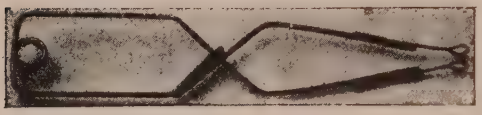


FIG. 106.—Localisation forceps, by Dr. J. Belot (small model).

FIG. 107.—Localisation forceps by Dr. J. Belot (large model).

The following is the method of procedure. The patient is placed on a table and after a quick preliminary screen examination he is fixed in the first position chosen. The diaphragm is partly closed and at the same time the tube

* We have taken this description from the article by J. Belot and H. Fraudet, "Localisation of Projectiles" (*Journal de Radiologie*, t. II. no. 1, Jan.-Feb. 1916, pp. 1–18, with 14 illustrations).

is moved about in its frame or on its stand until the shadow of the projectile to be localised occupies approximately the centre of the illuminated surface. The ring pincers are then taken and the arms opened by pressure, the limb is then taken hold of at a convenient level, and the pincers are gently moved about, without pulling the skin, until the image of the rings covers or surrounds the image of the foreign body. At that moment the hand which holds the pincers stops pressing and the two rings close on the skin. The current is stopped, the light is put on again, the screen is taken away and by means of a skin pencil or of a thermo-cautery, etc., the same mark is made (for instance a cross) in the centre of each ring.

The limb is rotated as far as possible through an angle of about 90° and in this new position a second determination, similar to the first one, is undertaken, but the two marks traced on the skin differ from the former ones, *i.e.* two points are made. Innumerable variations of the same

FIG. 108.—Rod provided with a metal ring used for localisation.

process, the principal of which goes back to the discovery of X-rays and seems to have been explained in detail for the first time by Morize * in 1898, have been proposed Instead of Belot's forceps, which we have just described and the use of which is particularly convenient and rapid we can also use a small board or some rod (sufficiently long to enable the hand which handles it to be outside the radius of the rays) provided at one of its extremities with a metal ring (Fig. 108).

First of all we place this ring in the first selected position by means of the screen on the skin of the side of the limb which is nearest to the screen, in such a way that the shadow of the foreign body (or a prominent point in that shadow) is projected into the centre of the shadow of the

* Morize, " A New Process for Determining the Position of Foreign Bodies by Radiography " (*Gazette des Hôpitaux*, February 19th, 1898).

ring and the point is then marked. The same manœuvre is then repeated for the side furthest away and the point is then marked (Fig. 109). The limb is then rotated, and the process is recommenced in the new axis selected.

Many English radiologists proceed in this way following Mr. Hernaman Johnson.* By operating simultaneously with two rods or strips of a similar size we come back to the Belot forceps (see Fig. 109). We can also use a rod at the end of which is fixed a buck-shot which is applied to the desired point of the skin, and which is kept motionless until that point has been marked. Finally we can also use for the same purpose the spintermeter rod which is very convenient for exploring under the screen. We thus avoid complicating our apparatus. Let us also point out as belonging to the same order of ideas and to finish the subject the practical use of two ink-markers which Gallot places simultaneously on the skin, one at the point of entry and the other at the point of exit of the normal ray.

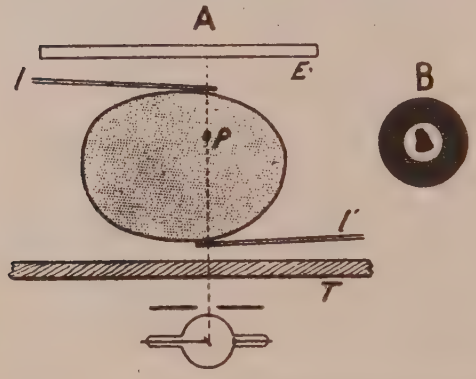


FIG. 109.—Showing how we mark on the skin the points of emergence of a normal ray passing through the projectile by using two rods with rings as shown in Fig. 108. In *B* we see the image which is seen on the screen *A* when these rods have been correctly placed.

It is also possible to mark the points by placing opaque guiding marks on the skin and by fixing them with some adhesive material, but this manner of proceeding does not in our opinion offer any advantage unless it is a case of taking plates and of making marks by another method.

These few indications seem to us to be sufficient, but we

* F. Hernaman-Johnson, "The Localisation of Bullets and Shell Fragments" (London, Lewis, 1915, broch. in 8vo. Cf. also *Foveau de Courmelles C.R.* 1915, t. 160, p. 97), who has only applied the same method also used by M. Debierne, etc., etc.

do not pretend to have indicated nearly all the old and recent variations of the Morize process.*

The tracing of four marks is generally sufficient to show the situation of a fairly large projectile, provided that the localisers have been placed in quite different directions to each other and as nearly as possible at right angles to each other, because it is evident that if they cross each other at a very acute angle the position is from a practical point of view badly determined. It is also of course necessary to place them perpendicular to the axis of the part of the body examined, in what Belot rightly calls a "right section," because this gives the surgeon the most accurate information.

But if the operator wishes to know the depth of the projectile in relation to the different possible points of incision before making his choice, or if he wishes to visualise the exact situation of a small projectile, we can easily give him satisfaction by perfecting our technique. The radio-profundometer of Réchou, the Menuet appliance, the Debierne method, the Vergely method give us easily the means.

The first of these instruments also plans out the axis of localisation by means of crossed wires (made by Gallot).

The Menuet Process.†—The principle of this method is to X-ray in two different positions but in the same part and perpendicular to the general direction of the body or limb in such a way that the normal ray passes through the projectile, then mark on the skin the entry and exit of these normal rays and draw by means of a special "cyrtometer" the outline of the body or limb and plot out the normal

* It is of course evident that when practising radioscopy we must never omit, in all these cases, to look for the point of the skin nearest to the projectile, which in general is very easy, at least in the case of the limbs. By pressing the surface of the body with the spintermeter or with our marking needle (Chapter XIII), we shall find the point at which the projectile is most easily movable. A description of the Coste process will be found in the *Lyon Chirurgical* (August 1916). This author, employing two distinct tubes, takes two plates exactly at right angles, and then establishes, by means of these two plates in a graphical method, the anatomical position of the projectile.

† T. Menuet, "Localisation of Projectiles by means of a Special Marker" (*Acad. médic.*, March 9th, 1915, *Arch. électr. médic.*, March 1916).

rays by metal rods, when the cyrtometer is taken off the patient and readjusted on a horizontal plane.

In order that the cyrtometer should not be twisted during the various manipulations the author has superimposed on each other two belts, one consisting of pieces of wood stuck on linen and the other of steel blades. In order to be able to adjust it and to take it off easily the cyrtometer is divided into two halves joined together by a hinge

The Debierne method * requires only a very simple geometrical diagram. Suppose we have already marked on the skin of the patient the four points B, B' and R, R' which determine the two axes which intersect at the projectile.

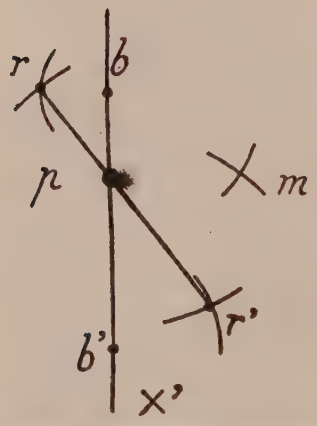


FIG. 110.—Geometrical diagram of the Debierne method.

We cut off the straight line XX' (Fig. 110) and trace on a rather large piece of paper (a quarter size is always sufficient), a length bb equal to BB' and this length is marked out in blue pencil. In order to measure this distance BB' exactly on the body of the patient a pair of compasses with curved points (Fig. 111) and of rather large dimensions should be used. We avail ourselves of dividers with curved points which are particularly well suited for this purpose: these are the dividers used by sculptors and designers in order to take similar measurements of models and mouldings Otherwise it will be sufficient to fix on ordinary dividers two rods in order to obtain a compass with movable arms which will render the same service. Or else the compasses described later on (§ 34) can be used.

Starting from the point b as centre, we trace with the compass an arc of a circle having a radius equal to $B\ R$, and then starting from B' another arc of a circle of a radius equal to $B\ R$ These two arcs meet at the point r which

* Debierne, "On the Method of Localising Foreign Bodies by Radioscopy" (*Presse medicale*, Marcn 4th, 1915)

has, in relation to small b and b', the same position as R in relation to B and B.

We obtain the point r similar to R' in the same manner by tracing from b as centre an arc of a circle with a radius equal to $B\ R'$ and from b' as centre an arc of a circle with a radius equal to $B'\ R'$: the meeting-point of the two arcs gives r. We can also obtain this point, for purposes of verification, by tracing from r an arc of a circle of a radius equal to $R\ R'$ and from b an arc of a radius equal to $B'\ R'$.

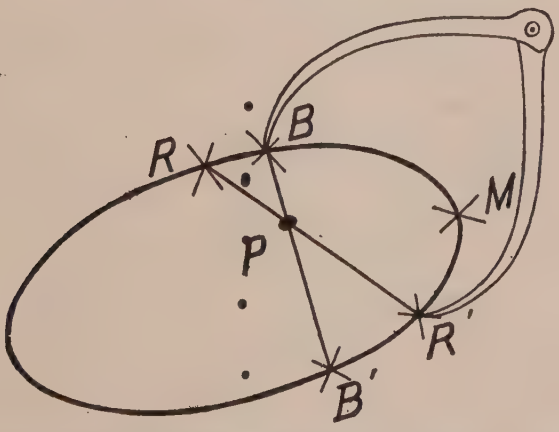


FIG. 111.—Graphical determination of the seat of a projectile by the Debierne method.

It is sufficient to join $r\ r$ (by means of a red pencil) which meets $b\ b'$ at p in order to obtain the position of the projectile and consequently its depth.

This position can also be verified by the tracing of a third axis passing through the point P. We can also trace on the same sheet of paper several points indicating the latest aspect determined by the plane passing through the red and blue axes, for instance the point m corresponds to the point M (Fig. 111) which will be the nearest to the projectile or which the surgeon has decided to be the best place for future operation. It is sufficient to mark the point M on the skin of the patient and to describe from the points b and b' as centres two areas of a circle with radii $B\ M$ and $B'\ M$ intersecting at the point m

The sheet on which the preceding geometrical construc-

tion has been made may form part of the written report of the case. It constitutes an important document for the surgeon, because it gives him, combined with a radiograph taken in a convenient position, the necessary information for undertaking the successful extraction of the projectile.

*Vergely Method.**—This author has tried to render in a graphic manner the plane on which the projectile is situated, and to visualise that plane in such a way as to determine the depth and direction in which it will be necessary to

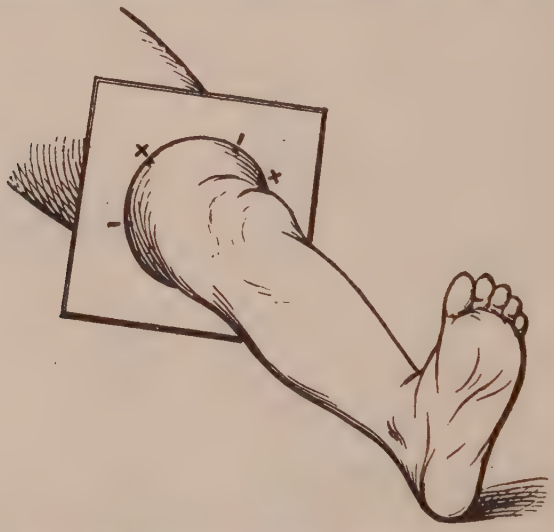


FIG. 112.—Inscribing the marked points on a piece of cut cardboard (Vergely process).

insert a needle or make an incision in order to find the foreign body.

For this purpose, after having marked the skin as previously described with the four marking points, he makes a hole in a piece of cardboard in which can be placed the limb or the part to be examined, which hole should be shaped as accurately as possible to the section of the limb where the marking points have been made. As soon as the card has been cut, it is placed in position and on its edge the exact position of the marked points is inscribed (Fig. 112). After this the cardboard is placed on a sheet

* Vergely, "Method for Accurate Localisation of Projectiles by Radioscopy" (*Presse médicale*, February 18th, 1915).

of paper lying on a table. The two crosses *B*, *B'* are then joined in a straight line by means of a ruler and then the two points *A*, *A'* are joined together by a straight line.

The intersection *C* of these two lines represents the position occupied by the projectile. We therefore can choose the point on the cardboard nearest to that intersection, namely *D*, and from that point *D* a straight line is drawn which passes through the intersection point *C* and which is continued on the piece of cardboard itself. The incision will be made at that point and in that direction *D' D*. Moreover, the direction *C D* represents exactly the depth at which the projectile is lying.

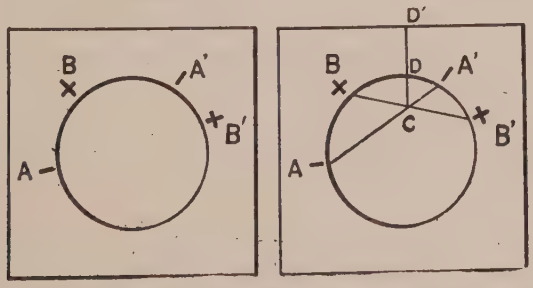


FIG. 113.—Graphical diagram in the Vergely process.

After this we pass on to the third phase in the process which must immediately precede the surgical operation.

The hands of the operator and the limb being rendered surgically aseptic, the distance *C D* is measured with an aseptic needle and is held with the nail on the needle.

The cardboard is then placed round the limb in such a way that the markings coincide. In order to ensure asepsis the edges of the cardboard may be covered with tincture of iodine. The needle is then inserted at the point *D* and in the direction *D' D* until the desired depth has been reached, that is to say where the nail presses on the needle. The needle is left in the soft parts and is used as a guide for the incision until the bistoury has reached the point and it then falls out by itself. This indispensable guide must not be taken out before the projectile has been found. If we wish to make more certain we may, after having inserted the needle, screen the region again to see whether it touches the foreign body.

This precaution, which is only useful for small splinters, can only be used for relatively thin regions, such as the neck or limbs ; but the principle of the method may serve even for the trunk, where it will give a useful idea of the depth.

§ 34. **The Compass** *.—In the course of operation, whatever the technique by which the localisation has been effected, the surgeon may need some precise guide, in order to give him at this moment an indication as to the exact site of the projectile and to guide him mechanically by means of a rigid metal pointer to the foreign body, the existence of which has been determined either visually (screen examination), by sound (telephone, La Baume-Pluvinel's telephone probe), or by touch (electro-vibrator).

Instruments, which enable the surgeon to perform this mechanical guiding and which are known under the name of compasses, are now very numerous and were invented some considerable time ago, because in 1899 M. Contremoulins (see p. 153) made a model of them and M. Massiot another model in 1900.

The later models consist of essentially an indicating needle which guides the surgeon as regards direction and depth and which he can regulate in its course, after the depth of the projectile under the skin has been determined and the marking points indicated which enable the apparatus and the accessory pieces supporting the needle to be conveniently arranged.

Some of the instruments allow the guiding to be done only in one invariable fixed direction. These are useless. Others on the contrary offer the great advantage that the foreign body being considered as the centre of a sphere we can materialise it by a metallic arc.

The indicating rod represents the radius of the sphere. It can be displaced both along the arc of the circle and also parallel to itself, so that it always points to the centre of the sphere and will touch it when completely pressed down.

Finally, these compasses have been mostly constructed in order to be adapted for the methods of localisation already described, although with some experience they may

* See art. by M. Beclere (*Paris médicale*, February 5th, 1916, p. 186).

all be used almost without exception, whatever the method adopted, whether radioscopic or radiographic.

Some are therefore constructed for the method of intersecting axes : we shall describe rapidly the most interesting and best known of these varieties. Others have been constructed in order to be applied to the method of displacing the tube : we shall refer to them after describing that method.

The Belot Compass.—A description and a diagram of this ingenious instrument used to guide the surgeon in the extraction of projectiles located by the " forceps method " will be found in the *Journal de Radiologie* (1916, No. 1).

The Debierne Compass *.—In order to define on the patient himself the direction and depth of the projectile after localising it according to the above-described Debierne method, we can advantageously use a compass which its author had constructed by Messrs. Drault & Raulot-Lapointe. It is nickel-plated and can be sterilised.

At the ends of a metal arc (Fig. 114) are two rods *t t* bent and terminating at their extremities in a point. They are so arranged as to be freely movable at will and to allow of their ends being superimposed on any given points, such as say *b* and *b'* which limit the axis of localisation. An arc *C* is cut out in the middle to allow of the movement of the piece *G*, which carries a tube in which there is a grooved rod *t'* terminated at one of its extremities by a point, and

* In order to fix the position of the compass still better the surgeon can add another rod *t'* beside the rod *t'* and place it in such a way that its point rests on a point marked on the skin in a convenient position, whilst the extremities of the rods *t*, *t* are always at the points *B* and *B'*.

This rod also enables the compass to be used during the operations by placing it on different points from those which have been determined directly by screen examination, and which may at that moment be inaccessible.

For that purpose it is sufficient to arrange the compass on two selected points of the figure constructed in the diagram, and to place the point of the indicating rod *t* on a third point of the same figure. Then transfer the compass to the patient in a corresponding position which is determined by the three points coinciding with the corresponding markings and then mark on the patient in a convenient position a fourth point on which is fixed the point of the fourth auxiliary rod *t* . . . . It is then possible to free the indicating rod ; it may be displaced on the arc *c*, still remaining in the direction of the projectile.

at the other by a milled button which enables it to be moved about in following the ray It will be understood,

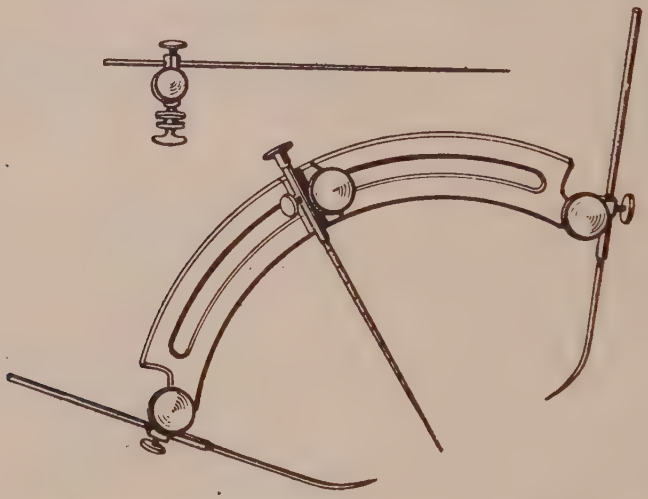


FIG. 114.—The Debierne Compass (Drault & Roulot-Lapointe, manufacturers).

FIG. 115.—The adjusting of the Debierne compass on a wounded man.

by looking at the figure, that as soon as the extremities of the needles *t* and *t* coincide with the two points *d* and *d'*

of the localisation axis, the extremity p of the movable rod will always lead to the projectile, whatever the position of that rod in relation to the arc C.

In order to use the compass after completing the graphical construction (Fig. 111) the position of the rod t of the compass is so regulated on the drawing that the point of the compass coincides with the point p, thus showing the site of the projectile; then the position of the rods t t is regulated so that their points fall, say, on the points b b' which are the extremities of the blue axis.

If the compass is now placed on the patient in such a manner that the points of the rods t t coincide with the blue points B B' marked on the skin, the amount by which the

FIG. 116.—The Cadenat apparatus which represents the simplest form of a compass.

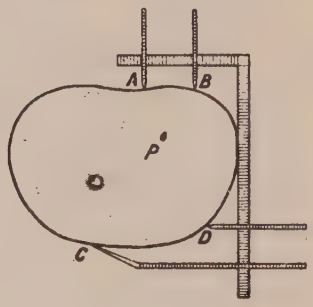


FIG. 117.—Diagram of the localisation arrangement of the Saïssi compass (compare Fig. 120), which effects the localisation by two intersecting axes.

point of the rod t' is displaced in order to touch the skin will indicate, by direct reading of the number of the divisions on the rod, the depth of the projectile in a direction which will be that of the rod itself.

It is therefore possible to choose the orientation of the corresponding rod at the most favourable point for operation (Fig. 115).

The "sector-guide" of Grandgérard has the same number of rods as the Debierne compass, but the three rods which form a tripod are grouped at one of the extremities of the arc.

Moreover, the indicator rod has at its upper extremity a small detachable spirit level.*

The F. M. Cadenat Apparatus.†—This author has described a rough-and-ready "compass" which can be easily made anywhere with a thick and thin wire and a knitting needle (Fig. 116). But it seems that all the units which may have to extract projectiles offering any difficulties are already fitted up pretty well at the present time so as not to have to make use of improvised appliances.

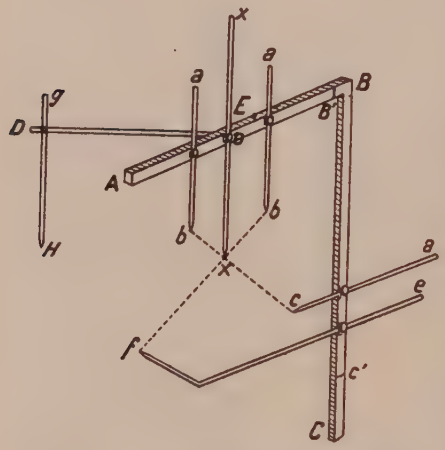


FIG. 118.—Diagram of the method of regulation of the indicator rod *xx'* of the handle *g* (see Fig. 120) of the Saïssi compass.

The Saïssi Compass.‡—The diagram 117 shows the theory

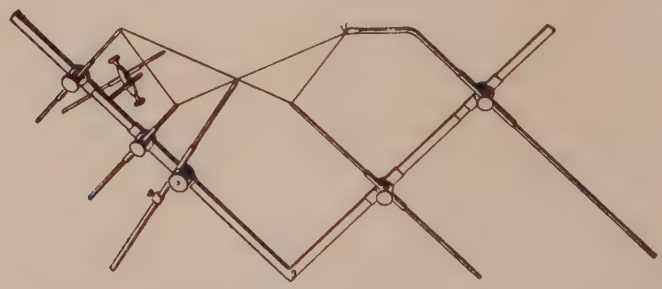


FIG. 119.—The compass of Saïssi set.

of the apparatus. The diagram 118 and the figures 119

* We have taken these few remarks from the article by M. Béclère already mentioned, as we have not before us that instrument constructed by Messrs. Malaquin & Dutertre.

† F. M. Cadenat, "A Simple Apparatus for Localising Foreign Bodies" (*Presse médicale*, February 14th, 1916, p. 67).

‡ See Albert-Weil, "Localisation des projectiles" (*Paris médicale*, February 5th, 1916, p. 130).

and 120 indicate the demonstration by crossed threads of the situation of the projectile and the regulation of the indicator rod *xx*. It is also necessary to have the handle *gh* which enables a third cutaneous marking point to be obtained, the other two being supplied by the extremities of the rods *bb*. Finally Fig. 121 shows us the "surgical" part of the instrument placed into position for operation.

However convenient and sufficient the principle of

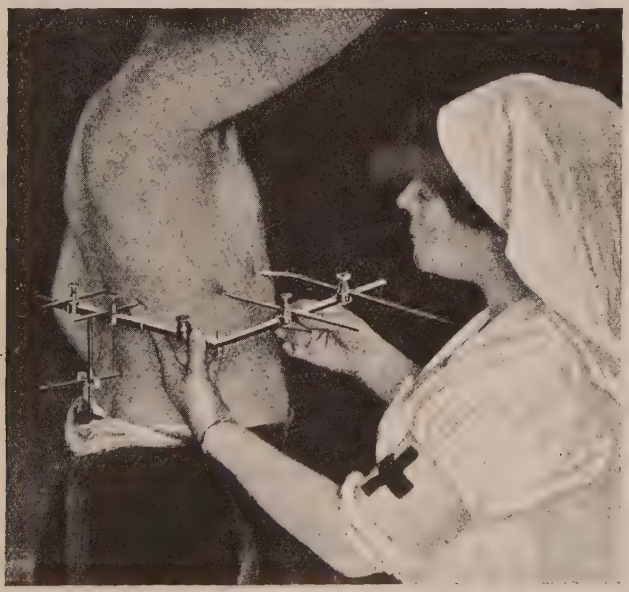


FIG. 120.—The arranging and regulation of the Saïssi compass on the patient. (Plate by Dr. Henry Béclère.)

marking by two intersecting axes may be in a large number of cases and especially for the limbs and however useful the guiding appliances based on the use of these processes may be, we must not disregard their serious defects. In fact they cannot be applied or are not sufficiently accurate (owing to the insufficient spreading of the axes) in all thick parts, that is to say in a large number of the most important cases. They cannot therefore claim to be generally applicable. We therefore formally advise the plan of

abandoning them in favour of techniques which we are now going to explain and all of which depend so to say on localisation by displacement of the tube.

Bibliography.—We could not possibly give complete bibliographical references with regard to localisation processes relating to Chapters VIII and IX. We shall content

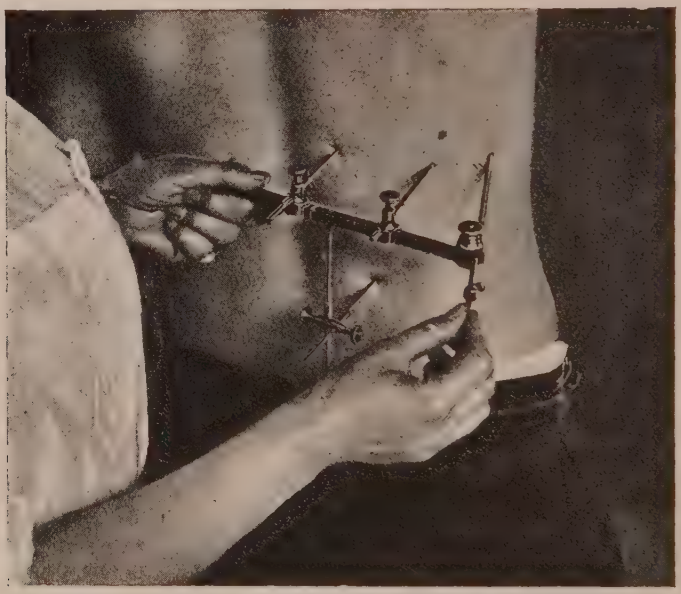


Fig. 121.—The use of the surgical part of the Saïssi compass. Verification before the operation. (Plate by Dr. Henry Béclère.)

ourselves by referring the reader to the excellent articles by Lebon (*Progrès médical*, 1915) ; Charlier (*Journal de Radiologie*, 1915) ; Albert-Weil (*Paris médical*, 1914—1916), from which we ourselves have taken numerous extracts, and to the collection of the *Journal de Radiologie*, the analyses of which will supply useful and ample reading.

CHAPTER IX

LOCALISATION OF PROJECTILES (*continued*)

METHOD OF THE DOUBLE IMAGE

§ 35. **Generalities on Localisation by the Double Image.**— The localisation processes derived from this method, which has already been explained from the theoretical standpoint in Chapter VII, give the whole of the qualities required for rendering its application really general.

What is it that we require of them ? Firstly a series of primary conditions : (1) It should be possible to effect the localisation in the operation position according to any direction indicated by the surgeon. (2) We must be able to apply it to every projectile the dimensions of which permit of its removal in the region under consideration. (3) It must possess an accuracy which should be sufficiently practical, that is to say in our opinion the error should not exceed 10 per cent. But it is absolutely useless to expect an absolute theoretical precision when —in view of the fact that the human body is not a rigid and motionless solid—in practice there occur variations which often reach—and sometimes exceed—10 per cent. and which thus deprive the localisation of its strict value (see also Chapter XIII).

Moreover present circumstances give a primary importance to two conditions which in time of peace are of secondary value : First, rapidity of application, and secondly the simplicity of the process. We may also mention, as interesting though secondary considerations even at present, the economy and the small elaboration of material together with the security of the radiologist ; these are all points discussed elsewhere and on which we shall not insist here.

All these considerations make us always prefer (see

§ 31) radioscopic processes to radiographic processes, both when it is a question of the double-image method or of the intersecting-axes method. We shall also see that they may be applied as well to the regulation of compasses—especially of Hirtz's—and their value will therefore be felt more and more, whilst the plates will supply us with all the important information which they can give us, if we take either the recognised front and side views or two stereoscopic plates. (See Chapter X.)

Screen localisation methods based on the process of the double image constitute by far the most numerous group. Since the war they have multiplied enormously. We shall consider them first and study the radiographic processes afterwards. There is however no fundamental difference between the two. Whether the measurement of the distance between the two shadows is indicated on the surface of a fluorescent screen or on the gelatine of a plate, the method remains the same. We shall describe later on the Hirtz compass and some other localising instruments.

We think that the information given in this chapter will be sufficient to enable any attentive reader to understand the theoretical principle of each process, and to select from the methods recommended by us the one which best suits his personal requirements. But these descriptions are given to prepare him for practical work, which is indispensable, and to facilitate it but not replace it. We have therefore given only brief and superficial descriptions of apparatus always dry and difficult to understand. The described instrument is not before us, so we have described as fully as possible the points which could be applied to the majority of methods and which are of general interest. Although we have tried to give a complete list of the different methods, we have described fully only those which appear to us to be really interesting and we have not tried to give in detail the smaller instrumental changes which have appeared since the war.

We only hope that the present impossibility of making serious bibliographical research has not caused us to make many important omissions, and we wish to apologise in advance for those we may have made.

It will be noted that we have discussed the localising methods used by our English colleagues and by those of

other allied nations to a very small extent. We ask them to believe that this is not due to our ignorance of their processes or to want of appreciation of their value, but simply because our space is limited and this work is addressed especially to Frenchmen and we thought it would be preferable to describe for our readers appliances which they would probably have at their disposal than others not so well known to them, however excellent they might be.

Finally we must strongly advise beginners to practise for a long time, after having made a choice of a method, at first on fictitious foreign bodies and then to verify the correctness of their localisation, before commencing to put them into practice on wounded men. They should always be careful to see to what extent the information given has been correct, by being present as often as possible at operations even if they have not the opportunity of collaborating constantly with surgeons in their extractions as we would advise them to do. Seeing that the extraction of projectiles involves an operation of some importance, neither beginners nor old practitioners should ever neglect to verify the depth found either by an examination of plates, front and side views, or by the process indicated later on. Owing to the value of experience we think that it is better to keep to a method which may perhaps not be so perfect, but with the working of which we are perfectly well acquainted, than to keep changing the method employed. Finally it must never be forgotten that the determination of the depth must be accompanied in every possible case by a complete X-ray and clinical examination (see Chapters V and XI).

We also wish to mention that from now onward we shall only consider in this chapter the recumbent posture as the position for localisation. We shall therefore not mention it again.

1. Radioscopic Methods

In France it is to Haret that the credit is due for the real revival of these methods as well as for the idea of the first simple and general technique. Almost all the numerous perfections introduced since the war in the

employment of the double image under various forms by so many authors are derived from it.

In order to co-ordinate to a certain extent the enumeration of the processes which are based on this method, we shall at first consider those which depend on a comparison of shadows given by the projectile and by an external foreign body the situation of which can be directly appreciable and which use in general the displacement of the shadow but without measuring its displacement. Then we shall describe the processes based on the classical equation (p. 147) and finally we shall consider some special solutions.

We wish moreover to point out that it is possible to use also the displacement of the shadows in order to return to the method of two straight lines which intersect. Let us place (Fig. 122) radioscopically two metallic indices A and B on the two opposite faces of the part of the examined body in such a way that their two shadows and the shadow of the projectile become merged on the screen.

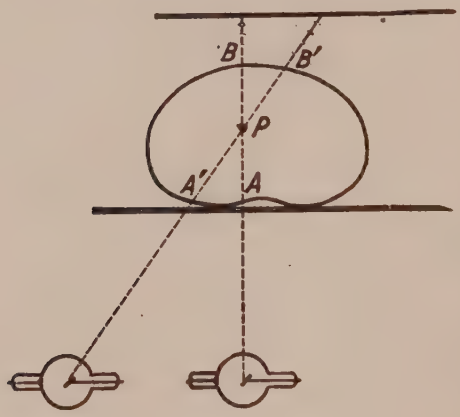


FIG. 122.

Let us displace the tube on one side or on the other side, and let us recommence to place our two marks—either A' or B'—in such a way that they superpose their shadows again over the shadow of the projectile. We shall thus have marked four points which when joined intersect at the level of the projectile P, and we thus come back again to the process of two axes. On the other hand, if we mark BB' by a, $A'A$ by b and the thickness—which can be easily measured directly—of the wounded part by h, we obtain the distances BP or AP by the classical formula $\frac{ha}{a+c}$ and $\frac{hc}{a+e}$ whilst $BP + AP = AB = h$ which gives

us a verification and brings us back under a somewhat modified form to the method of displacement of shadows.

§ 36. **Radioscopic Processes using the Displacement of the Shadow without measuring it.**—It is evident that, for the same displacement of the source of rays, the shadow of an opaque body on the screen will move away from its first position the more, the nearer the body is to the source, that is to say the deeper it is. If we have an opaque body external to the body and if we use it as a term of comparison it will supply us with an easy means to estimate indirectly the depth of the retained projectile which we are trying to find. It is, in general, on this

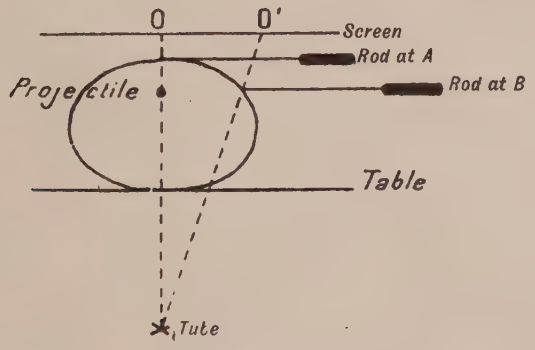


FIG. 123.

elementary method of ascertaining that the following processes and other similar ones, which we do not consider necessary to describe, are based.

*Knife Process.** — Popularised in France by M. Béclère this process is essentially a localising process. It consists of two stages. In the first one we determine usually by means of the point of the spintermeter (position of the rod at *A* of Fig. 123) the point of exit on the skin of the normal ray passing through the projectile, that is to say *O*. In the second period we leave the extremity of the rod on the place marked and move the tube.

The image of the projectile on the fluorescent screen

* Also called the process of the metallic rod (see Charlier, *Journ. de Rad.*, 1915, p. 580).

becomes displaced. The image of the rod which is nearer to the screen is displaced much less. But if it is gradually lowered along the body of the patient it will be displaced more and more as it is moved away from the screen. By either lowering or raising the rod gradually along the body we shall find that at a certain moment the amount of their displacement coincides. (Position at *B* of the rod on Fig. 123.)

At this moment the foreign body and the extremity of the metal rod are in the same horizontal plane, and the track of that plane can be marked on the skin. We shall thus have an indication of the depth we require. It is said that an English radiologist who employed this method placed a coin in a thick book and by using a knife as a rod (whence the name of this process) inserted at each attempt the blade exactly between the two sheets of the book which contained the coin.

In spite of its apparent exactitude this is only a rapid method of approximation or a makeshift process if no special instruments are at hand.

*Le Faguays Process.**—He uses the knife process but by his method it is possible to measure the depth instead of simply guessing it. The apparatus (Fig. 124A) consists of a vertical rod *c* fixed on a base, on which slide two cursors through each of which passes a wooden ruler which may be displaced horizontally, the rods and rulers being graduated in millimeters. The upper ruler *F* is terminated at one of its extremities by a metal ring, the lower one *H* is a lead point (Fig. 124).

The marker is placed near the wounded, the two horizontal rulers being perpendicular to the large axis of the region to be examined.

At first we determine the normal ray passing through the projectile and the extremity *F* of the upper ruler is placed on the skin in such a way that the shadow of the projectile is centred in the metallic ring and the ruler which determines the point *A* is fixed (Fig. 124C).

Thereupon the diaphragm is opened and the lower ruler is placed at such a height that *H* touches the skin and that the shadows of *H* and of the projectile face each

* Le Faguays, "Note sur un appareil de localisation de projectiles" (*Journ. de Rad.*, 1915, p. 711).

other. By displacing the tube perpendicularly to the direction of the rulers the former process is used in order to adapt the position of *H* to the same depth as the projectile. This distance is read off on the rod *C* (Fig. 124c).

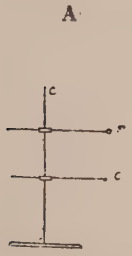


FIG. 124A.

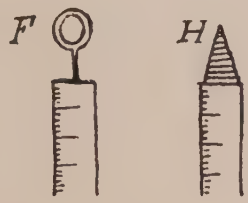


FIG. 124B.

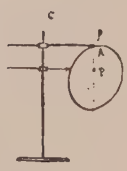


FIG. 124C.

This process evidently shares all the defects of the preceding one.

*Process and Apparatus of Morin and Le Maréchal.**—The patient being placed in position for operation the situation of a point *O* of the projectile (Fig. 125) will be defined by the normal ray *ION* passing through that point and through the distance *IO* from that point to the surface of the table. Let us suppose a spherical surface which has its centre in the projectile supposed to be reduced to the point *O*. Any line *MO* at right angle to that surface will pass through the projectile. These data are used by means of the apparatus represented schematically on Fig. 126.

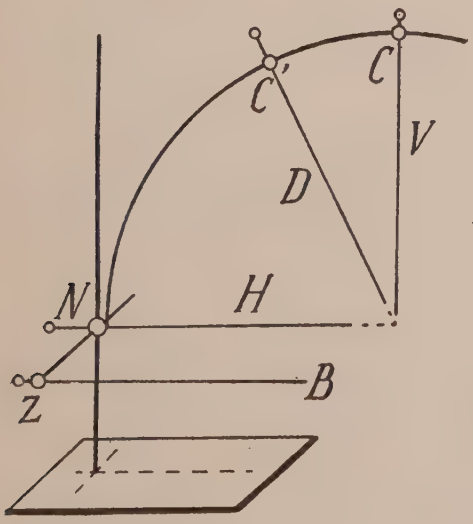


FIG. 125.

* Le Maréchal et Morin, "A New Apparatus to Localise Projectiles in the Wounded" (*Journ. de Rad.*, 1916, p. 102).

On a graduated vertical column there can be moved a slide *N* carrying several parts which are also mobile: (1) A horizontal rod *H*. (2) An arc which is a little more than a quadrant of a circle attached by one extremity to a ring which can turn round *H*. The arc in its rotating movements describes a spherical surface with the centre *O*. (3) A horizontal scale carrying at one end a socket in which there slides another horizontal rod the pointer *B*.

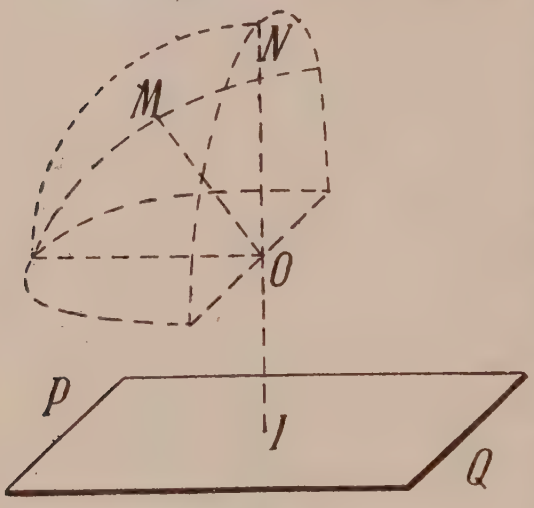


FIG. 126.

On the other hand the mobile arc carries two slides *C*, *C'* which glide on it and themselves carry other rods *V*, *D*, at right angles to the arch and situated on its plane. At the end of their course the rods *H*, *V*, *D* touch at the centre of the arc *O* and *D* (the directing rod is always directed towards the centre).

The supporting column may have another slide carrying a horizontal fluorescent screen on the surface of which are engraved in black, on the under surface, lines parallel to *H* and to the long axis of the screen (Fig. 127). The attachment is made in such a way that the vertical plane determined by *H* cuts the surface in an eccentric line (base line)

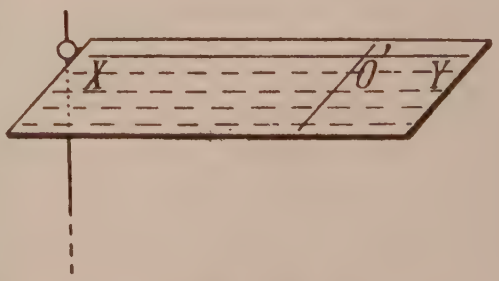


FIG. 127

whilst another line perpendicular to the former ones cuts the base line at the projection O' of the centre of the arc on the screen (principal point).

In order to effect the localisation the rods V, D are withdrawn and the arc is inclined in order not to interfere with the working of the screen which is fitted on the supporting column. The projectile is found and centred. Thereupon the principal point O' of the screen is also brought into the central ray. The centre of the arc is now situated on the vertical of the projectile, and we recognise the straight line *ION* of the Diagram 125. Moreover the shadow of H is formed on the same base line as that of the projectile.

In order to find the level of the latter the tube is displaced perpendicularly to the direction H. The shadows move in an inverse direction which indicates the one in which it is necessary to move the slide in order to bring the shadow of H on the same base line as that of the projectile, that is to say to place the rod H at the level required. When this is done the centre of the arc passes through the projectile itself and the localisation is made.

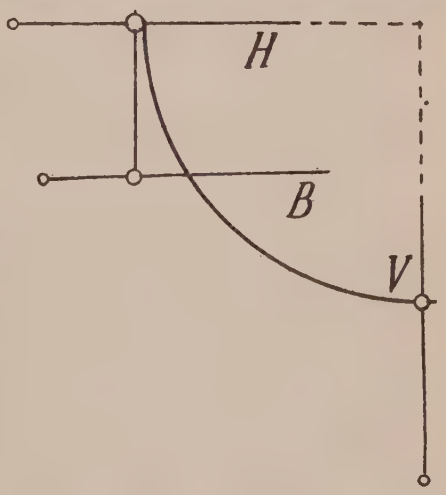


FIG. 128.

In order to find again later on the position of the projectile we make on the skin of the patient three marks, the positions of which are determined by the compass, the screen is taken away, V is replaced, the arc is brought back into the vertical plane. The rods V and H (which if prolonged would meet at the projectile) are pushed down to the surface of the skin and their points of contact RV and RH with the skin are marked, and finally with the rod B we mark the third cutaneous marking point RB chosen at random.

To obtain a permanent record of this curve, the height

of the nut on the supporting column should be noted, the arc is lowered on the rod *B* so as to place *VHB* on the same plane and a piece of paper is placed underneath and on it is traced a sketch similar to that of Fig. 128

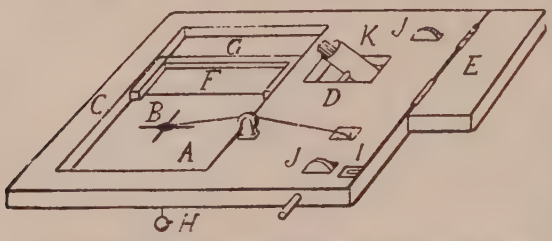


Fig. 129.—The pierced screen of Hirtz and Gallot (Gallot & Co., constructors).

The pierced screen of Hirtz and Gallot (Gallot & Co., manufacturers) can be recommended for its simplicity and ease of working. It is fixed (Fig. 129) by means of a piece *E* to which it is joined by hinges which enable it to be held in the screen carrying clamp of any X-ray table and to be moved in three directions at right angles. The apparatus has the following accessories: A mobile wire *F* stretched on a holder *C* which moves in an opening in the frame of the screen. A thin thread wound on a rod forming a windlass worked by two milled discs *J* and *J'* passes through the hole *B* and terminates in a small leaden ball *H*. Usually this ball is held in a clamp *I*. Finally in *K* a receptacle on a pivot contains small pieces of thin wood (matches). The bottom is provided with a plug soaked in thick ink.

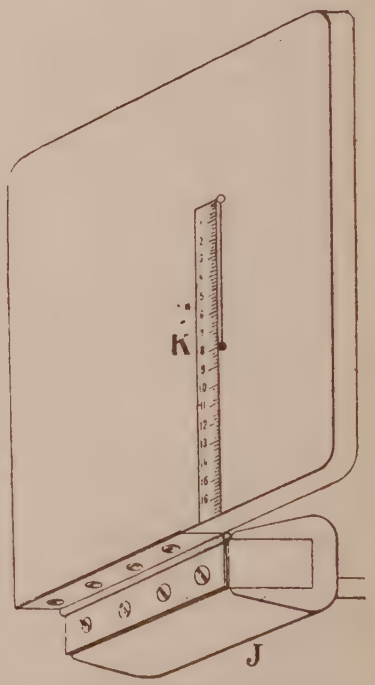


Fig. 130.—The pierced screen of Hirtz and Gallot fixed into the rod supporting the screen and lifted in order to effect the measurement of the length of the thread which gives the depth of the projectile.

In order to use this screen we must at first make certain that the tube is centred absolutely correctly, and that the pencil of rays which it emits when the diaphragm is almost entirely closed is quite vertical.* Then the patient is placed on the table in the required position.

(*a*) The screen is then placed by moving its supporting arm at a small distance above the region containing the projectile.

(*b*) The shadow of the projectile is then made to coincide with the middle of the luminous spot of 3 to 4 cm. in dia-

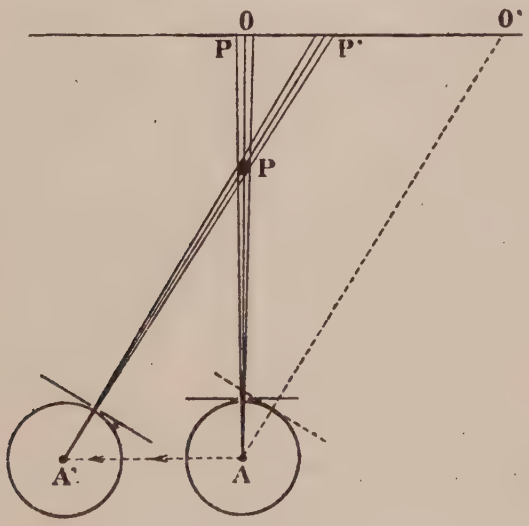


FIG. 131.

meter produced by the vertical pencil of rays by moving the tube.

(*c*) The screen is now displaced in its frame until the black spot produced by the hole is brought into coincidence with the middle of the shadow of the projectile or with an outstanding point of its outline. The two crossed black lines greatly facilitate the centring.

(*d*) Next the current going through the tube is cut off ; one of the wooden rods contained in the receptacle contain-

* See Laquerrière, Sluys and de Rolland on the importance of centring the tube in this process (*Journal de Radiologie*, 1916, p. 174).

ing the thick ink is passed vertically through the hole in the screen until it touches the skin. The path of the normal ray will thus be marked where it emerges from the skin.

Fig. 131 enables one to understand the principle of this process.

The tube A projects vertically at O on the hole in the screen E the shadow of the projectile P. The rotation of the tube deviates the luminous pencil to O'. It is brought back to O'' by sliding the tube to A' until it passes again through the projectile P.

As soon as the patient has been removed the ball on the thread descends through the hole O until the image reaches O'' (the position of which is determined by the mobile wire F). The ball will then be exactly at the point P, that is to say at the very same place which was occupied in space by the projectile.

§ 37. **Radioscopic Processes including the Measurement of the Displacement of the Shadow.**—The processes which we are going to study now and which form by far the most numerous and the most important include in their technique the measurement of the distance between the shadows produced in two successive positions of the tube according to the classical formula of depth $x = \frac{ha}{a+d}$.

In view of the importance of this procedure we shall give in detail the general method of applying it, enabling it to be used by any radiologist who has nothing else but an X-ray couch with a mobile tube under it and a screen which can be fixed above it at a desired height.

Suppose (Fig. 132) S to be the patient placed on the couch T in position for operation, P the retained projectile the depth of which we wish to discover.

We shall begin by placing our tube accurately centred previously in such a way that the projectile is in the normal ray and we shall mark on the skin the points of entry B and of exit A of that normal ray. Suppose O to be the position of the focus of the anticathode.

Then we mark on the lead glass which covers the screen E some point C which can be easily found again of the shadow of the projectile, say the point if it is a bullet (we should avoid taking the centre because of possible errors

in determining it exactly and of mistakes this may cause in the estimation of the depth).

Let us now displace our anticathode from *O* to *O′* (Fig. 133) and let us measure the distance *OO′* and presume that *OO′* equals say 11 cm. The shadow of the bullet will be displaced. Suppose *D* to be the new position of its point. Let us measure *CD* which will equal say 2·3 cm.

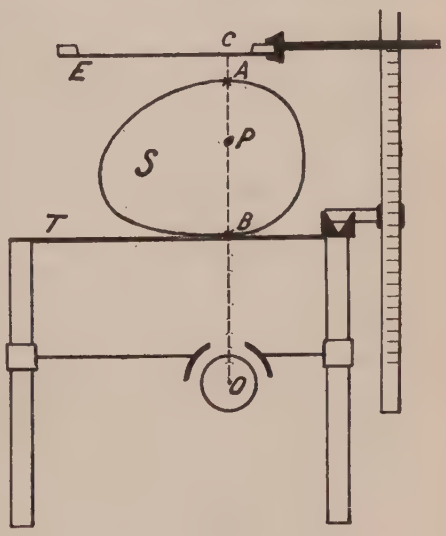


FIG. 132.

Let us measure the distance *OC* from the anticathode to the screen, say 64 cm. the depth of the foreign body will be supplied to us by the classical formula from which we shall only have to subtract the distance *AC* (say 3·1 cm.) from the screen to the skin (Fig. 132) with which the screen cannot always be in contact. We shall thus have:

$$X = OC \times \frac{CD}{CD + OO'} - AO$$

that is to say in the example chosen:

$$X = 64 \times \frac{2{\cdot}3}{2{\cdot}3 + 11} - 3{\cdot}1 = 11{\cdot}7 - 3{\cdot}1 = 8{\cdot}6 \text{ cm.}$$

and our foreign body will be at a distance of 8·6 cm. or 86 mm. above the point *A*. We have presumed the distance *AP* to be smaller than *BP* and we have made the localising mark on the side from which it is at the least depth which is logical and customary. Let us suppose that it is a thoracic projectile which is thus localised from the front. Let our patient now turn over and place himself on his abdomen and let us determine

the depth again, this time from the back. We shall thus obtain the depth *BP*, say 13·2 cm. We have thus determined *AP* and *BP*. We only need to add these two quantities in order to obtain the length *AB* (here 8·6 + 13·2 = 21·8 cm.). But we are also able to *measure directly* this length very easily by means of callipers (or by means of any similar appliance easily improvised). This is an excellent and valuable control of the correctness of our localisation and we should always use it whenever the projectile is deep or is situated in a difficult region. It is

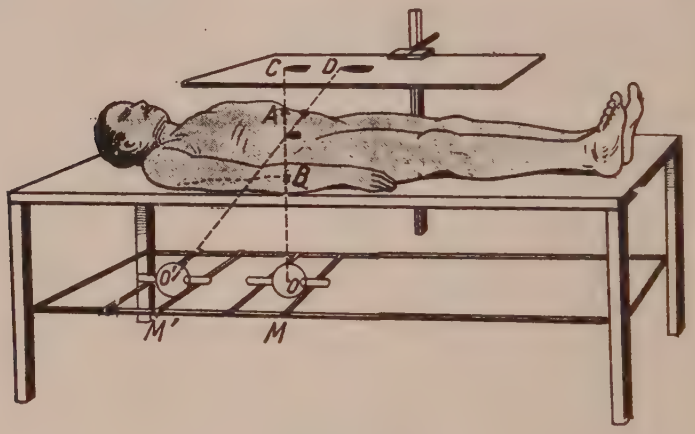


FIG. 133.

evident that we cannot expect an absolute similarity in the figures for *AB* found by these two methods, but that difference should be within reasonable limits otherwise we should repeat our localisation which for some reason or other is too inaccurate.

This procedure may certainly be used in the way we have just described. But it is very slow and there are many causes of error. We will therefore discuss, by adding our practical experience to the theoretical considerations described in Chapter VII, the various measurements to be made and try to find any possible simplifications of the technique.

1. *Distance from Anticathode to Screen.*—The distance from the anticathode to the surface of the table is measured once for all directly; say it is 33 cm., thereupon we place

a centimeter scale on the support carrying the tube in such a way that the figure 33 is on a level with the top of the couch. When the support is raised we can read off the distance of the anticathode to the screen on the scale. It is evident that we shall take it for granted that the focus is situated at the centre of the anticathode, and that we shall consider that it coincides with the centre of the sphere of the tube. As this hypothesis is never realised absolutely exactly there will be some slight error which can be ignored in practice because to obtain greater accuracy would introduce unnecessary complications. This measurement should however be verified each time that a new tube is used. We can see at once the considerable simplification of calculations which will result from adopting a constant distance from the anticathode to the screen, say 50 or 60 cm. It becomes a simple matter if we also adopt (see later) a constant displacement of the tube to prepare scales which give the depth of the projectile by direct reading of the displacement of its shadow, or to construct isobathymetric curves which answer the same purpose.

Numerous authors have adopted this process of which we give later on an example by describing the Allaire apparatus. But in spite of its great apparent suitability we must not advocate its use in general, because the distance left between the table and the screen is not sufficient and often interferes with the examination of large patients, or else serious mistakes are caused owing to the large distance separating the screen from the skin during localisation on thin parts such as the hand.

2. *Displacement of the Tube.*—It depends on the suitability of apparatus at our disposal whether this displacement is made in the same direction or at right angles to the long axis of the X-ray couch. Here too an important simplification of calculations will be obtained if we adopt for the displacement a constant distance in every case, say 10 cm. The advantage of this is not attended by any inconvenience so we shall not hesitate to make use of it and we shall adopt in common with the majority of workers this distance of 10 cm.

It is extremely useful and almost indispensable if we wish to be able to effect this displacement rapidly in the

darkness of the X-ray room, without groping and without the possibility of a mistake, to add to the apparatus a special stop device enabling us to change the tube automatically from its first to its second position which is then fixed to avoid any error from an accidental movement. All manufacturers now produce similar appliances to be fixed to their couches but a simple block of wood will suit the purpose.

In order to avoid all calculation it is possible to materialise the data of the problem, as has been so ingeniously and very simply done by Haret.

The Haret Process *.—The tube is displaced at a fixed distance from the upper surface of the couch. The vertical gliding rod which supports the screen is graduated in centimeters in such a way that when the screen is fixed for an examination we read directly in millimeters the exact distance AB which separates the focus of the anti-cathode from the screen (Fig. 134). An angle block has been prepared in order to allow the displacement of the tube by 10 cm. in darkness.

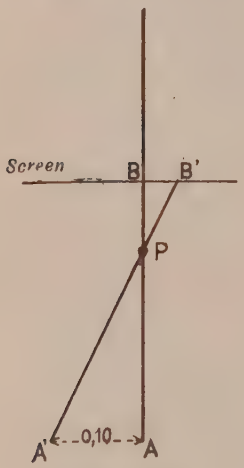


Fig. 134.

In order to localise we place the screen in contact with the skin on the region under examination, we allow the normal ray to pass through the projectile, we obtain on the screen a shadow which we mark with a grease pencil, and this is the point B. We then displace the tube along the slide by a distance AA' (which we have settled is to be 10 cm.) and the projectile gives us a second image B' which we also mark on the screen. We can measure the distance BB' of the two images of the projectile on the screen. The focus of the anticathode in its two displacements and the two images of the projectile are on the same plane as the projectile.

To obtain the depth of the foreign body all that is necessary is to construct in space the two triangles BPB'

* Haret and Schlesinger, " A Very Simple Apparatus for Localising Foreign Bodies " (*Presse médicale*, December 24th, p. 746).

and APA' which have two sides BP and PA in a straight line.

The sides BB' and AA' are perpendicular to the straight line AB, and we know by simple reading the distances BB' and AA'. If we join the points $A'B'$ by a string we shall obtain on the line BA a point P, the summit of the two triangles which is the exact point where the projectile

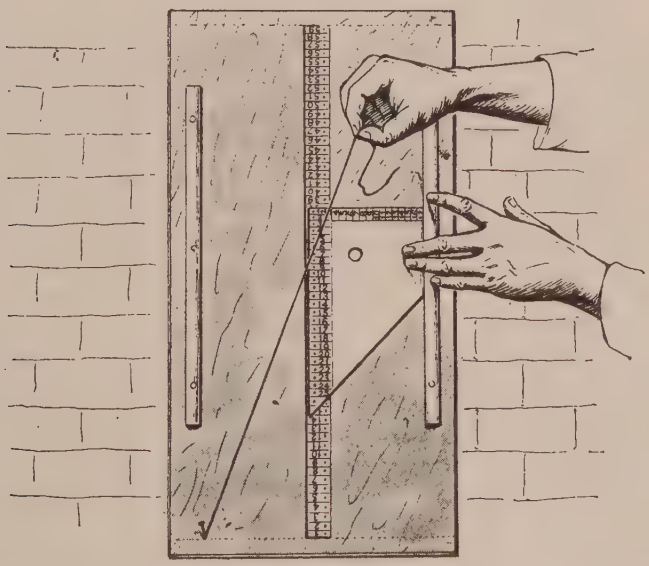


FIG. 135.—The Haret Apparatus (Gallot & Co., manufacturers).

is situated, the distance BP which we read easily is the distance from the projectile to the skin.

The following appliance is constructed in order to render the process practical: A dressmaker's measuring tape is pasted on a small board (say the cover of a coil), one side only, say the left side, being taken into consideration (Figs. 135 and 136) in order to apply it to the line AB and at A' a thin thread is placed. A set square is then taken and the two sides of the right angle are graduated in centimeters. The finding of the position of the projectile will be very simple. For a thickness AB we place the top of the square angle of the square at the point B corres-

ponding to the number of centimeters indicated by the support of the screen. On the side BB' we take the figure of the variation of the shadow of the projectile. If we join $A'B'$ with the thread this thread cuts the line AB at a point P so that PB is the distance from the projectile to the skin.

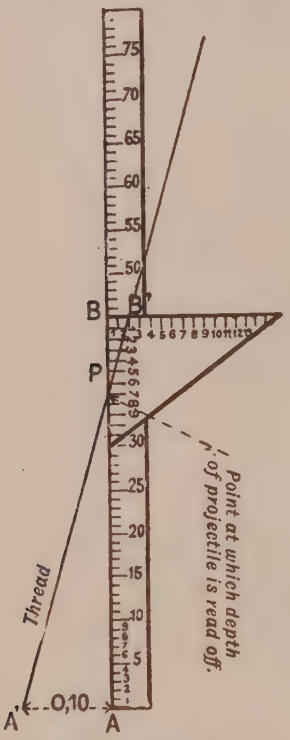


FIG. 136.—The Haret appliance.

Should we for any reason whatever not be able to place the screen in direct contact with the skin we carry out the same procedure but we must measure the distance between the screen and the point on the skin where the normal ray emerges. All we need then do is to subtract that distance from the figure given.

*The Jaugeas Process.**—A technique very similar to the preceding one has been simultaneously described by Jaugeas.

The Allaire Radioscopic Marker.—This marker consists of a rectangular frame opaque to the X-rays of 0·03 m. in thickness at a certain point of which there is a rectangular space of 0·12 m. in length by 0·06 m. in width divided into four parts by two crossed metal plates. A metal graduation is placed at the upper part which covers the two rectangular spaces. The vertical plate forms the zero of the graduation and the divisions increase progressively to the right and to the left of that plate. The graduation has been established by practice and calculation for a distance of 30 cm. from the anticathode to the screen and for a displacement of the tube by 10 cm.

If we wish to make use of that appliance, it is placed at a distance of 47 cm. from the anticathode. The screen will

* Jaugeas, *Presse médicale*, 1914, p. 743.

thus be at 50 cm. from the anticathode, as the thickness of the marker is 3 cm.

From a rapid examination with a fluorescent screen we determine the depth at which the foreign body is situated

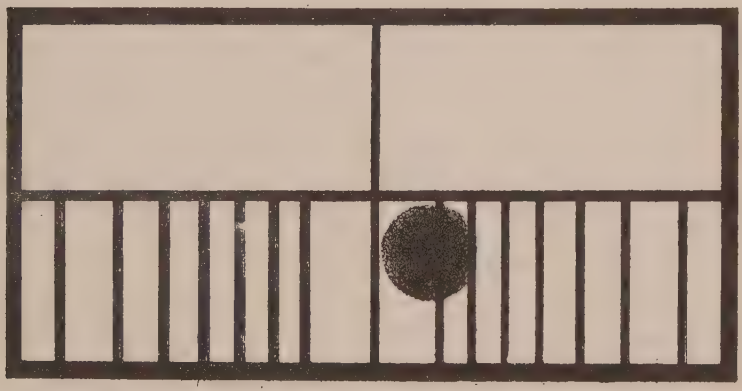


FIG. 137.

and the tube is adjusted to its level. The screen is placed upon the localiser and the tube is displaced in such a way that the metallic plate appears on the screen only in the shape of a line. The normal ray passes through the inter-

FIG. 138.

section point of these lines. In order to obtain these lines precisely the tube must be displaced successively from right to left and from front to back. Care must, more-

over, be taken when the patient is lying on the table that the shadow of the foreign body is placed in the opening made in the scale, coinciding with the horizontal of the vertical plate (Fig. 137). The tube is then displaced by 10 cm. say to the left. The shadow of the foreign body is displaced to the right and runs through a larger or smaller number of divisions corresponding to its depth. (Fig. 138). Each division passed represents a depth of 2 cm. from the foreign body to the skin. If the division is passed incompletely its value is represented as follows : half represent 1 cm., quarter 0·5 cm. If for instance the shadow has passed two divisions and a half the projectile is at 2·5 cm. from the skin.

The Londe Process.—To determine the distance at which the foreign body is situated from the plate without calculation and by simple compass measurement this author since 1898 has been using a wooden triangle. On the perpendicular dropped from the summit of that triangle there are fixed metallic rods of unequal length and separated from one another by a distance of 1 cm.

The patient is taken away from the radioscopic table, the triangle is placed in a vertical plane which passes through the foreign body, the tube is then displaced. The iron rods will throw their shadow on the screen, it is sufficient to read the division which corresponds to the localising mask left in place of the shadow of the projectile in order to know its depth. If for instance the two images of the foreign body are situated between the fourth and fifth rod, and if the rods are at a distance of 1 cm. its depth is about 4·5 cm.

This very simple process does away with a somewhat delicate measurement, namely the measurement of the distance from the tube to the plate.

§ 38. **Mazérès's Rule and its Simplification of the Calculation—Diaphragm Effect—The Skiameter—The Bathymeter.**—Let us point out that the classical equation $x = \frac{h + a}{a + d}$ may, if we adopt for the displacement d of the tube a constant distance, say 10 cm., be expressed in the form $x = Kh$.

We calculate for the various successive entire values of

K expressed in hundredths, the corresponding value of a:

$$a = \frac{100K}{1-K}$$

These values of a, expressed in millimeters, are placed on the ruler, starting from a common point, and they are numbered with a corresponding value of K. We have thus realised a scale which measures directly, in coefficients of K any length a.

This is the rule invented by Mazérès (Fig. 139) and its application to the localisation of projectiles is most advantageous because it enables a considerable simplification of our calculation even if we leave the distance of the anticathode to screen variable which we recommend. If we measure the displacement of the shadows on the divisions of the rule, the depth of the projectile will be obtained

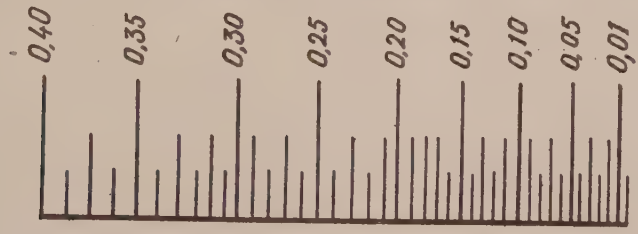


FIG. 139.—The Mazérès rule (we may of course increase the scale for any desired length).

by simple multiplication of the figure on the rule by the distance of the anticathode to the screen. It is only necessary to deduct from it the distance screen to skin and we shall only have had to do a direct reading (anticathode to screen) on a graduated scale and a simple measurement (screen to skin).

But even if we employ the rule as a ready reckoner which reduces all calculations to a single operation—a very simple subtraction—the method is capable of two serious objections which however may apply to all radioscopic proceedings which we have so far described.

First of all there is the relative inaccuracy of the measurement of the displacement of the shadow. The marks made in pencil, or with a stylographic pen, etc., on the

plate of the screen lack precision, they are too thick or indistinct, etc., and may produce errors of reading which, when added up, may easily reach 2–3 mm. and sometimes more. And we have seen (p. 149) what a serious effect these errors have on the final results.

It was therefore necessary to find a process for measuring the displacement of the shadows which would enable us to avoid these errors. Messrs. Viallet and Dauvillier have successively solved this problem by effecting this measurement by the method of adaptation of optical shadows, the precision of which is well known. Moreover the observer is freed from any causes of error resulting from the graphical marking of the screen.

On the other hand when the tube is displaced if it is a question of finding a very small projectile situated in a thick region or in a fat subject the projectile, very visible when the diaphragm is closed as far as possible, can sometimes be seen only with difficulty when owing to the 10 cm. displacement it is necessary to open the diaphragm to follow its shadow. It may happen that under these conditions it becomes quite invisible. The localisation therefore becomes a matter of guess-work and the displacement of the image is measured incorrectly or else is not measured at all. These cases have induced certain surgeons, and even certain radiologists, to state that it is impossible to devise a general method for screen localisation whereas the failure is due to inadequate and faulty technique. We have already said, and we repeat it, that if the diaphragm is properly handled any projectile which can be extracted surgically is visible. All that we have to do is to apply the diaphragm-effect at all stages of localisation. We shall now see how Messrs. Viallet and Dauvillier on the one hand and M. Dessane on the other hand have solved this problem.

The Skiameter of Viallet and Dauvillier.—This apparatus (Fig. 140) which is perhaps the most precise of those founded on radioscopy was devised and produced by its inventors in the last months of 1914. It is specially suited for the outfit of the X-ray lorries, Gallot type.

Its essential parts are: (1) A rule with a stop device fixed on the horizontal bar of the tube carrier to effect automatically the displacement of 10 centimeters (Fig.

141). (2) An elliptical lead cylinder having at its upper part a small fluorescent screen and provided with a network formed of two plates of lead crossing at right angles which cut out the embarrassing effect of the secondary rays and at the same time allow a direct sight of the prominent points of the shadows. (3) A square section tube having

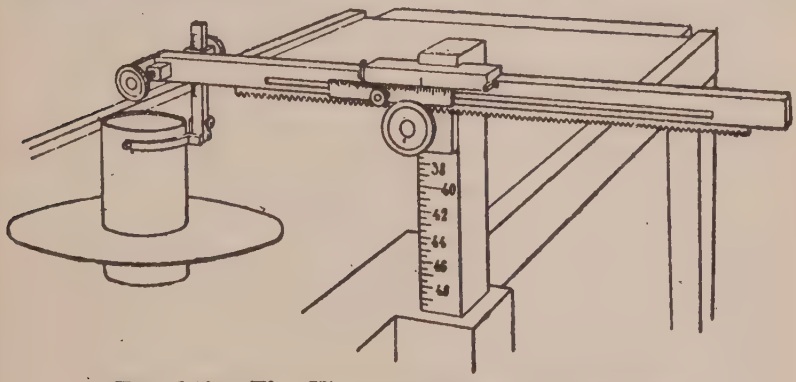


FIG. 140.—The Viallet and Dauvillier skiameter.

a double rule of Mazérès type; on its extremity is fitted the oval cylinder provided with its small screen. (4) Finally a wooden upright, carrying a centimeter scale giving by direct reading the distance anticathode to screen, supports the whole.

To start with, the localisation includes as usual the centring of the projectile in the line of the normal ray and the determination of the point of exit of that ray on the skin (called by Vialiet the marking of the projectile on the surface) and which is carried out with any ordinary screen. The cylinder of the skiameter is then placed directly above the marked point and if possible it is placed in contact with the skin (position *A* of the tube, Fig. 142).

FIG. 141.—The stop device of the skiameter. It allows a displacement of five centimeters on each side of the normal ray.

The tube is then displaced by 5 cm. to the right, which can be carried out automatically with the stop device (posi-

tion *A'*, Fig. 142), the opening of the diaphragm is increased and the shadow of the projectile will be seen on the small screen. By means of the regulating screw the first " sighting " is made by making an outstanding point of the shadow of the projectile coincide with the transverse line of the network in the cylinder. The Mazérès ruler is moved by lifting the stop which kept it fixed and the tube is displaced by 10 cm. towards the left (this is effected

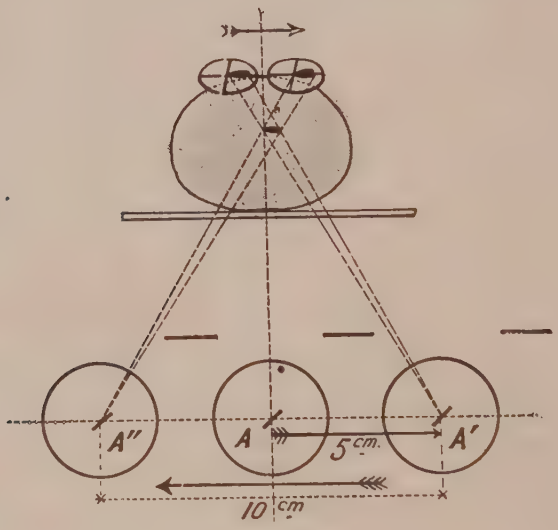


FIG. 142.

automatically owing to the stop device) (position *A''*, Fig. 142).

Then we make the second " sighting " by making the same point of the shadow coincide with the same line in the cylinder, by means of the rack on the support, the Mazérès ruler will be displaced and in order to find the desired depth it will be sufficient to multiply the coefficient obtained on the ruler by the distance anticathode to screen (read off from the upright) or else to consult a previously established ready reckoner which indicates that product. As the height of the cylinder is 100 mm. the result obtained should be reduced by 100. Should it not have been possible to establish contact between the cylin-

der and the skin, this distance after being measured should also be deducted.*

This process combines great precision with great rapidity and, owing to the use of the diaphragm-effect supplied by the cylinder and owing also to the displacement from one position to the other of the normal ray enables us to obtain an excellent view of even the smallest projectiles. Moreover it possesses as we have already said the advantage of measuring the displacement of the shadows by optical means.

The Localiser-Guide by Gudin † (Fig. 143), constructed by Drault & Raulot-Lapointe, has adapted the excellent principles of the skiameter to an apparatus giving the exact site of the projectile in space by attaching to it a mechanical guiding instrument, a compass. It also gives localising marks.

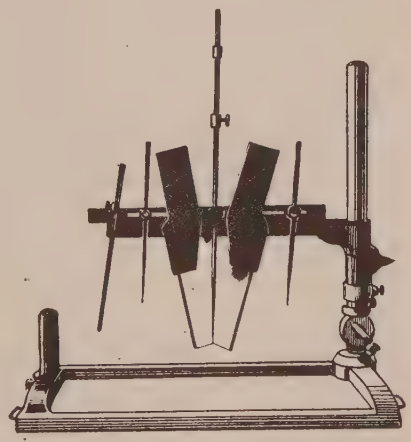


Fig. 143. — Localiser-guide by Gudin (Drault & Raulot-Lapointe, manufacturers).

The Radio-Bathymeter of Dessane seems to us to add to the advantages of the skiameter (precision, omission of calculations by the use of the Mazérès ruler and of ready reckoners, perfect visibility, etc.) a still greater facility of working and a certain simplification of apparatus, the screen used being 18 × 24 and lending itself, consequently, to a complete exploration of the patient without having to change

* It will be noticed that had the tube been guided by the vertical upright supporting the skiameter, thus making the distance anticathode to screen constant whilst avoiding the inconveniences mentioned above, a Mazérès ruler could be constructed which would immediately supply the depth of the projectile by direct reading. But this process which resembles very closely that of Barret described later on, unfortunately requires a complicated and little-known apparatus.

† Gudin, *Bul. Acad. Méd.*, October 17th, 1916, p. 294.

the apparatus. It is quite possible with a little skill to adapt our screen to make a rudimentary but working model of it ourselves and at small expense.

Finally, it facilitates perhaps more than any other apparatus the reading of the distance screen to skin which is often so difficult. It is very rapid, it supplies in even inexperienced hands exact and certain results and, in difficult cases, perfect visibility. This is the method adopted by one of us for all localisations carried out in the Central Service of Radiology of the ninth region at Tours.

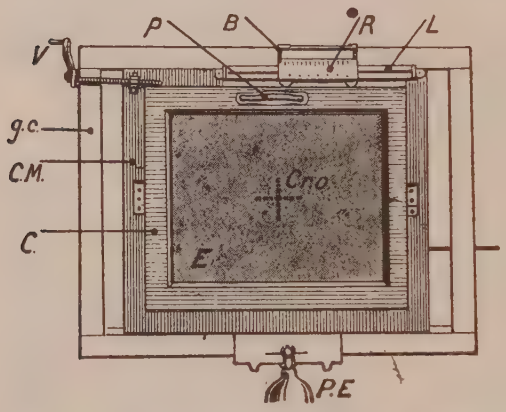


FIG. 144.—Radiobathymeter by Dessane (Gallot & Co., manufacturers). The model represented here is a makeshift apparatus constructed for the service of radiology of the ninth region. Figs. 68 and 69 give an idea of a much better model supplied by the constructors.

The bathymeter (Fig. 144) consists essentially of a screen 18 × 24 (*E*) fitted on a frame *CM* which is itself mobile by sliding in the interior of a second frame *gc*. The screen *AC* is fixed by hinges to the frame *CM* and can be lifted like a lid of a box, leaving thus absolutely free access to the underlying region (Fig. 145). The displacement of the mobile frame *CM* in the interior of the large frame *gc* and in its long diameter is produced by a simple screw rod *V* the rotation of which, either in one or in another direction, controls the direction to the right or to the left of these displacements. A Mazérès ruler *R* is moved with it. Its registering is mobilised when the stop *B* is lowered enabling thus the coefficient to be read (Fig. 148).

In the centre of the under surface of the screen *E* there is pasted an opaque cross-bar and on this surface a ready-reckoner has been fixed by which calculations are avoided.

These columns of figures will be seen in Fig. 145. A horizontal piece *PH* (Fig. 146*A*) which is placed in the mobile frame (Fig. 145) when the screen is lifted and carries a carefully centred orifice, enabling us to reproduce the normal ray by inserting in this orifice the rod represented in *B* on Fig. 146.

A stop device similar to the one shown for the skiameter but used for measuring the displacements of the tube made in the long axis of the couch completes the apparatus. To carry out the localisation, the apparatus is placed in the screen carrier (Fig. 147) and its horizontality verified; then the patient is placed in the required position. The procedure adopted is as follows:

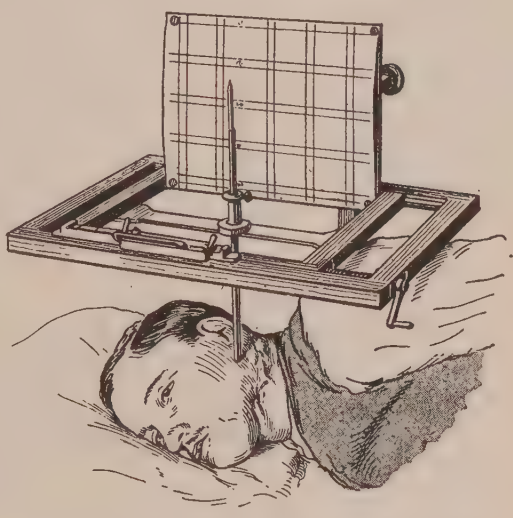


Fig. 145.—The Dessane bathymeter. The screen is lifted, we see on its under surface the columns of figures of the ready-reckoner (p. 232). The horizontal piece has been placed in position and the rod (Fig. 146 *B*) measures the distance screen to skin.

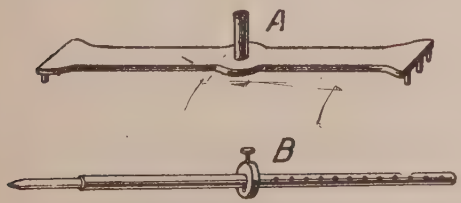


Fig. 146.—The horizontal piece *A* enables the rod *B* to be centred and the point of exit of the normal ray to be marked, and then by simply removing the rod *B* to obtain the distance screen to skin by direct reading very accurately (Fig. 145).

The centre—or any prominent point—of the shadow of the projectile and the centre of the opaque cross-bar are placed in the normal ray. The current is cut off, the screen is lifted and after placing into position the horizontal piece the exit of the nor-

mal ray is marked with a pencil carried by one end of the rod *T* inserted in the orifice *O*.

This rod is replaced and by letting its other extremity descend until it touches the skin (without depressing it), which contact is made of course at the point of exit of the normal ray, we estimate directly at the level of the ring *B* the distance screen to skin, the rod *T* being graduated in mm. This is the operation shown in Fig. 145.

The horizontal piece is taken away, the screen is lowered again, the current is put on again, and the tube is displaced by 5 cm. to the right (which is effected automatically

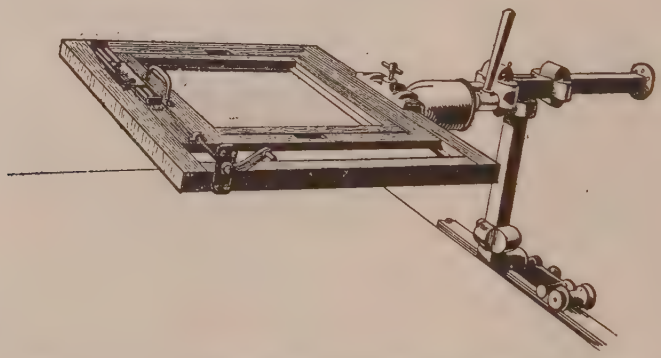


FIG. 147.—The bathymeter fixed to the screen carrier and ready to carry out a localisation.

owing to the stop device). The diaphragm is slightly opened and the opaque cross is placed in such a way that one of its limbs which is perpendicular to the direction of the displacement of the mobile frame (that is to say perpendicular to the long axis of the couch) is situated slightly to the left of a prominent point of the shadow of the projectile. Then by manipulating the screw rod *V* we make these two shadows coincide, thus reproducing the first "sighting."

The tube is next displaced by 10 cm. to the left, the stop (Fig. 148) is lowered and by turning (always in the same direction) the threaded rod *V* the contact (destroyed by the displacement of the tube) is re-established between the limb of the cross and the prominent point of the shadow. The operation is then terminated. The screen is then

lifted in order to have the ready-reckoner before our eyes (p. 232) the coefficient found on the Mazérès ruler is noted, say 13 (Fig. 148 *B*), the distance anticathode to screen on the

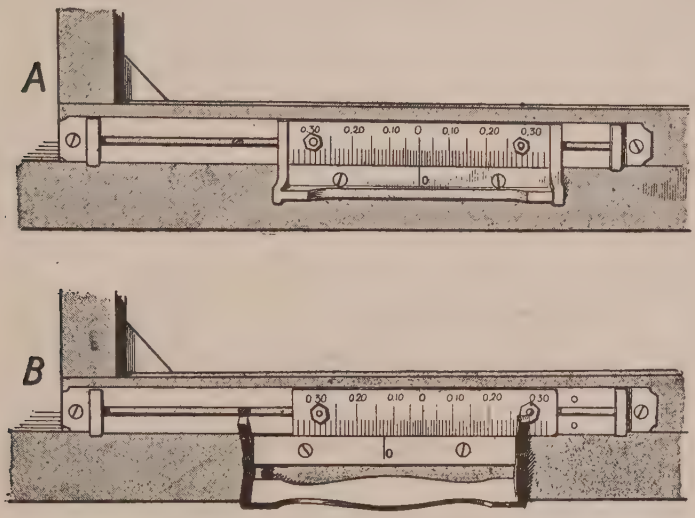


FIG. 148.—Details of the Mazérès ruler. At *A* the ruler glides on the frame, at *B* it remains stationary and the scale is only displaced over it when the stop is lifted.

vertical upright of the screen-carrier is taken note of (say 62 cm.), the ready-reckoner is consulted and we find the figure 80·6. It is sufficient to deduct from it the distance

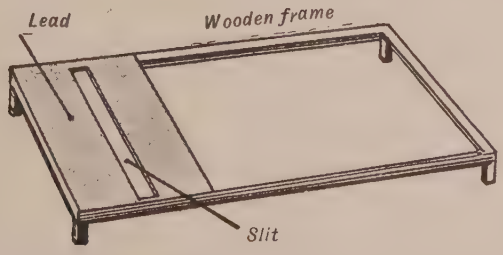


FIG. 149.—The diaphragm-slit of the bathymeter.

screen to skin read on the graduated rod, say 37 mm., in order to have the depth of the projectile in millimeters which would be here 53·6 mm. and we shall consider it to be 54.

If we find ourselves in the presence of projectiles which for some reason are difficult to see and which it is difficult or impossible to follow during the second displacement of the tube, we simply place on the tube carrier the apparatus of Fig. 149 by placing the open part of the frame above the diaphragm. As soon as the projectile has been found and centred, it is placed in such a position that the lead plate is situated above the diaphragm and that the projectile is framed in the slit of that plate. In this slit the shadow of the projectile is displaced with the displacement of the tube and the diaphragm effect thus produced allows perfect visibility.

The bathymeter which we have described and shown here is a relatively simple model which may be constructed almost everywhere. A considerably perfected model has been constructed by Messrs. Gallot (Figs. 68 and 69 give an idea of it) and is particularly suitable to be adapted on the radio-surgical couch of Ledoux-Lebard of which it constitutes an indispensable complement.

§ 39. **Particular Cases of Triangulation.**—The measurements, readings or calculations which have to be made in these various procedures which we have just described are not very complicated and only a small amount of training is required to apply them with confidence.

They may still however be the cause of errors for careless operators. Many inventors have therefore tried to eliminate them by estimating the determination of the depth by a single direct reading or a single measurement on the screen. We have already shown when describing the Allaire marker or the skiameter possible solutions of this problem, and we have also discussed the criticisms to which they are subject, and the reasons why they may not be considered suitable for general adoption in spite of their merits.

Some inventors have devised instruments capable of effecting all the necessary movements automatically.

In this connection we have seen a very ingenious apparatus invented by M. Biton at Cholet which is however too complex and overloaded for it to come into general use.

Others such as Messrs. Desplats and Paucot have constructed graphs with curves of equal depth. Mr. Quichard

has invented another radioscopic apparatus for direct reading (manufacturer, Rupalley), etc.

More interesting are however, to our mind, the attempts made by some to make use of particular cases of relations of identical triangles and thus to arrive at simplified formulæ or to introduce angular data according to the pattern of M. Guilleminot * in his radiogoniometer.

The Roussel Process (Figs. 149–150), (*Report of the XIth Region, February* 1916).—Suppose a tube is placed under the table. Let us place above the opening of the tube carrier upon the ordinary diaphragm (Fig. 150) a lead plate pierced by two orifices of about 1 cm. in diameter each, one *A* placed in the course of the normal ray to the plane of the table *T*, the other *B* made in such a way that the distance *AB* from its centre to the centre of the first one is in a simple relation, in preference $\frac{1}{2}$ or $\frac{1}{3}$, with the distance which separates the centre of *A* from the focus *F* of the anticathode.

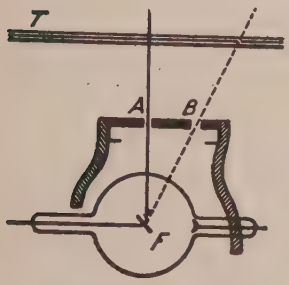


Fig. 150.

If, for instance, $AB = \frac{1}{2} AF$ we can write:

$$Tan\ AFB = \frac{1}{2}$$

and the angle which has this property is the angle 26° 33′ 50″

Let us suppose that the patient is placed on the couch, let us examine him, let us first roughly centre the projectile *P*

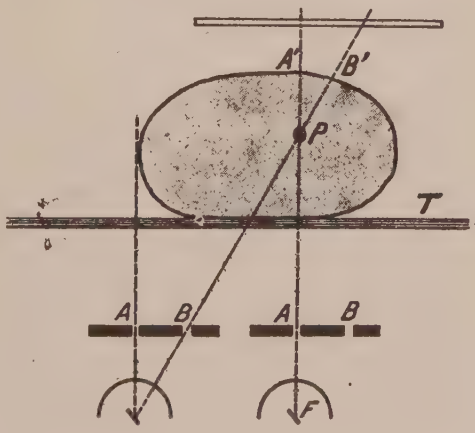


Fig. 151.

* Guilleminot, *Traité de radiographie et de radioscopie clinique de précision* (Paris, 1900).

with the ordinary diaphragm and then centre it in the orifice A of our lead plate, and mark the exit A' of the normal ray on the skin. Let us now displace the tube until the shadow of the projectile appears again on the screen, being shown by the rays now traversing the orifice B. Suppose B' is the projection on the skin (Fig. 151).

The triangle $A'PB'$ is a rectangle (because we can always obtain $A'B'$ on a horizontal), its sides are parallel to those of the triangle FAB, these triangles are therefore equal and we have:

$$\frac{A'B'}{A'P} = \frac{AB}{AF} = \frac{1}{2} \text{ whence } A'P = 2A'B'$$

The Strohl and Mary Mercier Processes.*—These authors have also recourse to particular cases of triangulation.

The Pierre Process.—Already indicated in detail in his remarkable article on localisation processes which appeared in May 1915, by Mr. Lebon † who says it was shown to him by Messrs. Gallot and Rivier, without knowing its real author, this process has been taken up again by Mr. Pierre ‡ from whom we take its description.

Let us consider a tube which may be displaced along a horizontal scale and may be turned round an axis also horizontal and perpendicular to the preceding scale; this tube is provided with a metal rod the direction of which passes through the centre of the small central plane mirror. In the displacement of the tube the centre of this mirror describes a horizontal line parallel to the scale. The part in which the foreign body is situated lying on the radioscopic screen, let us suppose that we have caused the vertical plane which contains the line on which the centre of the anticathode is displaced to pass through the foreign body M and let us take this plane as the plane of the figure. By means of a plumb-bob we place the metal rod in a vertical position; for any position of the tube we have on the screen: (1) a shadow of the rod situated vertically above it, (2) a shadow of the foreign body M. By displacing the scale in a convenient direction, these two shadows will be brought to coincide in a single point m and this

* Strohl, *Journal de Radiologie*, 1916, p. 173.
† *Progrès médical*, May 1915.
‡ *Académie de Médecine*, October 26th, 1915, *Bulletin*, p. 472.

point will be marked in pencil on the screen : the foreign body is situated on the vertical passing through that point.

The tube is then brought behind and is turned round its axis so that the metallic rod forms an angle of 45° with the horizontal and consequently also an angle of 45° with the vertical.

We shall still have on the screen two shadows : (1) the shadow of the rod reduced to a point ; (2) the shadow of the foreign body. By displacing the tube in a convenient direction we shall make these shadows coincide at *s*, a point which we shall also mark on the screen (Fig. 152).

We shall observe that owing to the equality of the angles at *M* and at *s*, *Mms* is an isosceles triangle and that consequently the sides *Mm* and *ms* are equal. By measuring the distance of the two points, *m* and *s*, marked on the screen, we shall obtain the length of the line *Mm*, that is to say the distance of the foreign body to the screen. The foreign body is therefore on the vertical which passes through *m* and above that point at a distance equal to *ms*, the length measured directly on the screen.

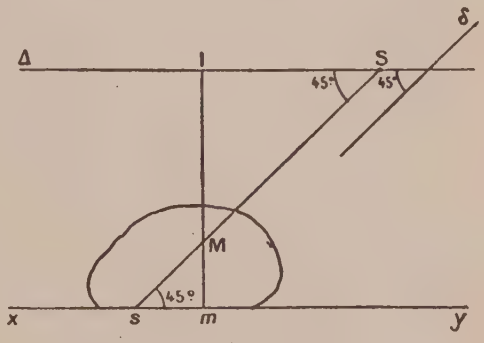


FIG. 152.

In practice it would be interesting to place the screen on the part which contains the foreign body and the tube above, which simply amounts to reversing the procedure.

§ 40. **The Barret and Andrault Process.**—This apparatus deserves special mention owing to its ingenuity and because it has the very rare distinction amongst these methods which are founded on the double-image idea that it is not based on the properties of similar triangles.

Let us suppose that we have a tube which in addition to its ordinary displacements in a plane parallel to that of the table, can also be raised (or lowered) vertically under the

table and the screen is attached to the tube, that is to say that it can be raised or lowered at the same time as the tube and that an upright graduated in millimeters enables us to read directly the value of these vertical displacements.

Suppose T to be the plane of the table, P the retained projectile. We centre it as usual on the normal ray. Suppose A_1 to be the position of the anticathode of the tube, E_1 the position of the fluorescent screen at the moment when the centring is effected. We place on the skin of the subject at the emergence of the normal ray a mark R which may be a metallic fragment which is attached by some adhesive or a rod, say the point of the spintermeter (the shadow of which is produced at p' at the same time as that of the projectile).

Let us displace now the tube by any desired quantity, in the same plane parallel to that of the table. Suppose A to be its new position. The shadow of the projectile will be produced at p'' and we shall mark it on the screen. The shadow of the cutaneous marking will be shown in n.

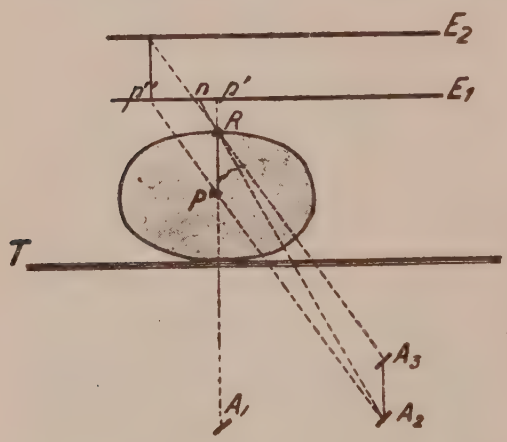


FIG. 153.

Let us now lift the tube and together with it the screen until the shadow of the marking again coincides with the point (p'') marked on the screen. The anticathode will be at A_3, the screen at E_2.

The figure shows us that the distance A_2A_3 measured by direct reading on the upright gives us the depth of the projectile (parallels included between parallels). Here we have no calculations, only a single mark to be made on the screen any displacement of the tube, no measuring of the distance screen to skin. It is therefore regrettable that

this method so attractive at first sight needs a special and rather costly installation and one difficult to make under conditions which ensure a constant rigid parallelism of the plane of the screen and of the plane of displacement of the tube which is an essential condition for a correct result.

Radiographic Processes

All the processes which we have so far described and based on the displacement of the tube were exclusively radioscopic. It will however be readily understood that the same principles can, as already indicated, be applied without any changes to the determination of the depth by radiographic means. In the latter case we shall measure the distance between the two shadows of the projectile on plates and not on the screen. On the whole this is only a simple difference in the technique. If various complications and an additional expenditure of time and money result therefrom, we are compensated by a greater precision—at least theoretically—and we possess a fixed and permanent image, which may be undertaken by anybody, and consequently free from the character of subjectivity of the radioscopic observation and of the personal factor which goes with it. It seems therefore that especially for the regulation of the compass, radiographic processes are the best, and up to the present this has been and still is the unanimous opinion of the greater number of radiologists and especially of surgeons.

However, we have said (§ 35) why we prefer good radioscopic processes the advantage of which are considerable especially in war time. They also allow the regulation and the use of compasses—such as the excellent instrument of Hirtz—with the advantage of rapidity, simplicity and economy, and at the same time of correctness, which have caused them to be immediately adopted for that use by most of those who have tried them, and we strongly advise their use by all radiologists.

Moreover, the majority of radiographic processes—for instance the Hirtz—presume a previous radioscopic examination, even if not a complete radioscopic localisation. They are not free from the dangers of radioscopy, slight though they be for those who take adequate pre-

cautions (see § 17), of which they retain all the inconveniences without profiting from its advantages. Therefore, in our opinion, radiographic methods can only justify their existence in two cases: (1) If the surgeon has no confidence in his radiologist and wishes to undertake himself the regulation of the compass, without having the time or the wish to carry out all the preliminary manipulations. He is given a plate according to which he regulates his instrument, but what confidence can he then have in the accuracy of the preliminary operations? (2) The radiologist is not a physician, he ignores radioscopy and is afraid to use it on account of its numerous sources of error, whilst he has learned the manœuvres of a radiographic process which enables him to supply a mechanical localising instrument to a surgeon who cannot or does not wish to practise the extraction of projectiles by means of the intermittent control of the screen, and even in the latter case the manipulator—as he does not deserve the name of a radiologist—would have to use preferably processes which include two separate plates enabling him to carry out a stereoscopic examination (see Chapter X).

*The Buguet and Gascard Process.**—These authors were amongst the first to apply to radiography as well as to radioscopy the classical formula which we have described on pp. 146–7.

Instead of measuring the displacement *a* on the screen they note it on the plate.

The Mackenzie-Davidson and Hedley Process.†—These authors seem to have been the first ones to materialise by an intersection of threads the situation of the projectile in space by using for the localisation two radiographic impressions made on the same plate.

Fig. 154 shows a July 1900 model of their apparatus. It is interesting to compare it to the apparatus of Marion-Danion shown later on. Their method, excellent at that period, has been in constant use since.

* Buguet et Gascard, C.R. Acad. des Sciences, 1896, "The Séchehaye Method" (*Bulletin médical de la Suisse romande*, 1898) is also a variation of the same principle.

† Mackenzie-Davidson, "A Method of Precise Localisation and Measurement by Means of the Röntgen Rays" (*Lancet*, October 1898).

The Mergier Process is based on the same principle as the preceding one, except that the shadows are recorded on two different plates.

The Contremoulins and Rémy Process.—Also basing themselves on the same idea but criticising the lack of precision of their predecessors these authors have elaborated an extraordinarily laborious and complicated method which certainly gives exact results in theory, but meets in practice with practically the same difficulties and with the same causes of physiological inaccuracy as the others. It is used only by its authors who had the merit of being amongst the first ones to complete the proper localisation by mechanical localising instrument, guiding the surgeon to the projectile by a compass which formerly rendered real services.

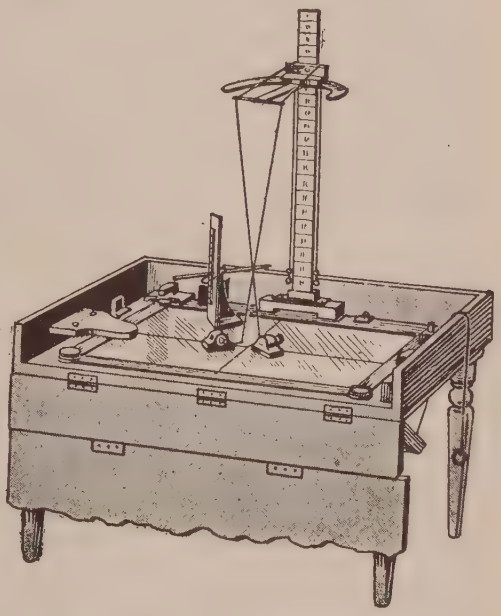


FIG. 154.—The Mackenzie-Davidson and Hedley Process.

*Colardeau Process.**—This author has revived and perfected an old process.

Let us mark on the skin of the patient near the point where a previous screen examination has shown us the projectile, a small cross *O*. Let us call it the "original marking" and let us imagine three rectangular axes passing through it. The axis of x will be parallel to the transverse diameter of the patient, the axis y to the long axis of his body and the axis z perpendicular to the preceding ones will traverse the patient. We shall determine the co-ordinates XYZ of the projectile in relation to this

* *Arch. Electr. Médic.*, March 1915, and *Presse médicale*, 1915.

system of axes. The two co-ordinates XY indicated starting from O on the surface of the body will indicate where the surgeon should make an incision in order to find the projectile at the depth Z. The two radiographs taken as follows will enable us to make these calculations.

A cassette similar to one which is used for stereoscopic radiographs, but on the upper face of which there is let into the wood an intersection of opaque metal wires, is placed under the region examined and it is made sure, by means of a plumb-bob, that the centre of the anticathode which has been placed 50 cm. above the plate (slid into the cassette) falls at the intersection point of the wires, *i.e.* the centre of the plate. Finally we place the region to be radiographed, which has already been examined with the screen, in such a way that the projectile is situated more or less in the centre of the plate. On the point of intersection we place an adhesive metal index on the skin of the patient, this giving us the point of the axis z. The other one is determined by the plumb-bob and at the level of the second point we mark with a dermographic pencil a small cross, the two branches of which follow the directions $xx'yy'$ of the two opaque wires of the cassette. The centre of this small cross will be the origin O of our three rectangular axes.

We displace then the tube (which was centred at O') parallel to the direction XX', by a quantity d in such a way that it is at A_1 and we take a plate in which the image of our projectile P is at P_1. Thereupon, after changing the plate without moving the patient, we displace the tube from $2d = 64$ mm. to A_2 position symmetrical to A_1 in relation to the initial position O' and we take a second plate on which the image of the projectile will be P_2.

The shadow of the intersection of wires traces on these plates (Fig. 156) the axis $xx'yy'$ and we shall measure directly, with a double-decimeter the distance x_1 from P_1 to the axes yy' on the plate C_1, the distance x_2 from P_2 to yy' on the plate C_2, the distance y from P_1 or from P_2 to the axes xx' on one or the other plate (this distance is evidently the same on the two plates). The depth Z' of the projectile (starting from the plate) is then easily

calculated. In fact, the two similar triangles of a common summit P (Fig. 155) give:

$$\frac{Z'}{D-Z'}=\frac{x_2-x_1}{2\delta} \text{ whence } Z'=\frac{D\,(x_2-x_1)}{(x_2-x_1)+2\delta}$$

that is to say with the adopted numerical values expressed in millimeters:

$$Z'=\frac{500\,(x_2-x_1)}{(x_2-x_1)+64}$$

If we wish to have the depth Z calculated from the point marked by the plumb-bob on the skin, it is sufficient to

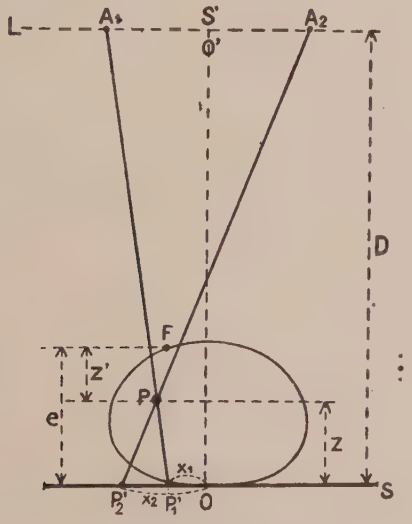


FIG. 155.

measure the thickness e of the member between the two markings and to deduct Z' from e; $Z = e - Z'$.

If we wish to have the two other co-ordinates X and Y, let us note that the two triangles $O'QP$ and $O'OM$ give:

$$\frac{X}{(x_1+x_2)}=\frac{D-2'}{D} \text{ whence } X=\frac{D-Z'}{D}\,\frac{(x_1+x_2)}{2}=\frac{(500-Z')\,(x_1+x)}{1{,}000}$$

The value of $2'$ being like that of X is immediately deducted from that expression.

We shall have Y in function of y by the same formula:

$$\frac{Y}{y} = \frac{D-Z'}{D} \text{ whence} = Y\frac{(D-Z')}{D}\ y = \frac{(500-2)}{500}\ y$$

In practice we shall of course make use of ready-reckoners.

The Bertin Sans and Leenhardt Process.—We can only mention in passing this process, called the process of graduated crosses, as well as the excellent process by Henrard (of Brussels), the ingenious appliances of Mazérès, of Miramond de la Roquette, etc.

The Belot Method.—Particularly interesting though

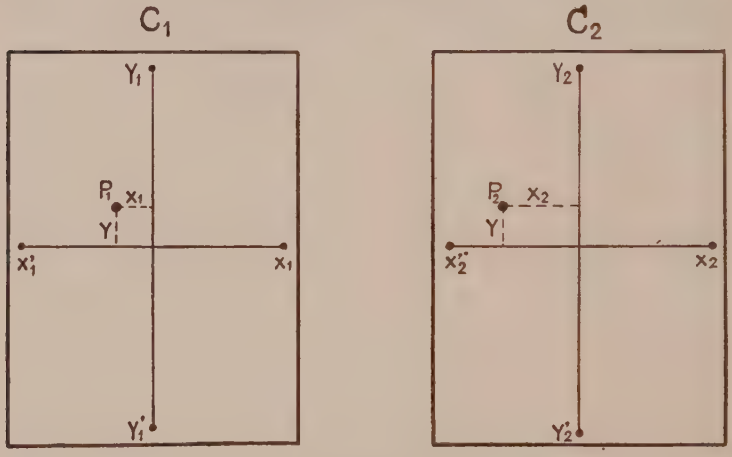
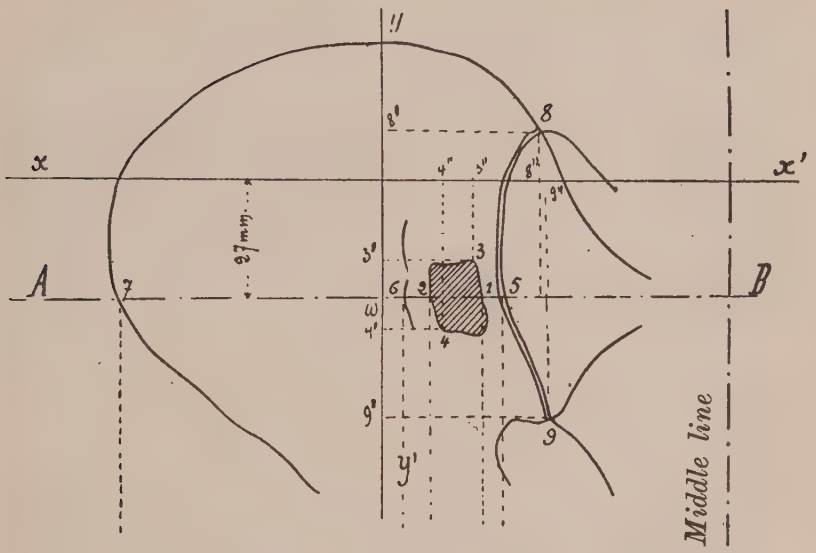


FIG. 156.

rather complex it indicates a localisation not as is the case with most other methods, in relation to a point on the skin always variable and capable of being depressed but in relation to the bones. This is at the same time an excellent method of anatomical localisation.

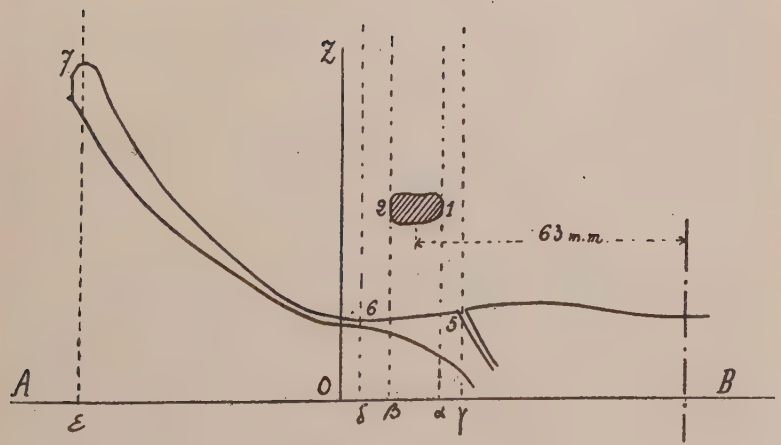
It is particularly valuable in certain difficult cases, for instance for projectiles of the sacro-iliac regions or of the iliac fossa, if we wish to know whether they are in front or behind the bone or included in its thickness. It is known that in these cases we may sometimes find ourselves in serious doubt as to the position of the projectile even if we know the exact distance which separates it from the skin.

Fig. 157 shows the instructions supplied say for a shell



Right iliac fossa (internal)

Anterior view



Section at level of A B

FIG. 157.—The Belot Method.

splinter of the right iliac fossa and shows the precise numerical and anatomical details which it is possible to obtain by determining successively the co-ordinates of the various chosen points of the projectile and of the skeleton bones on the diagram. For details of the calculations and for the ready-reckoners we refer the reader to the original article by Belot and Fraudet (*Journal de Radiologie*, 1916, pp. 1–18) as owing to lack of space we cannot, unfortunately, give here all the instructions relating to it or reproduce the ready-reckoners drawn out by the authors.

Process adapted to the regulation of a compass. A certain number of processes based on the method of the double image are essentially intended to be used in combination with some "mechanical guiding" instrument for the surgeon which we have already studied in relation to their modalities which are adapted to the method of intersecting axes (see § 34). The same general considerations may always be applied here. We are going to consider in detail their prototype, the Hirtz compass.

§ 41. **The Hirtz Compass.***—The Hirtz "localising compass" was invented in 1907 and is certainly to-day one of the best known as well as one of the best amongst appliances of a similar kind. The following are the considerations on which it is based (Fig. 158).

Let R be a sensitive plate: to its envelope is attached an index V' on which is centred with a plumb-bob the anticathode of the tube V. The region containing the projectile P is placed over the plate.

On the three points A, B, C, conveniently chosen on the skin, there are fixed metal markers. This focus of the tube is successively displaced from F to F' and from each of these points a radiograph is made on the same

* The following works should be consulted on this compass: E. J. Hirtz, "L'examen radiologique des blessés et la recherche des projectiles" (*Achives de Médecine et de Pharmacie militaires*, 1916). Morin et H. Béclère, "Simplification de la construction graphique dans la localisation des projectiles par la méthode du compas de Hirtz" (*Journ. de Rad.* 1916, p. 31). A. Charlier, "Nouveau procédé radiographique pour régler le compas de Hirtz" (*Journ. de Rad.* 1916, p. 43). R. Chaperon et J. Vanderhaeghen, "Contrôleur pour le réglage et localisateur de Hirtz" (*Journ. de Rad.* 1916, p. 46). J. de Poliakoff, "Quelques modifications à la technique de la localisation des corps étrangers à l'aide du compas de Hirtz" (*Achives de Bergonié*, avril 1916, p. 97).

plate *R*. Thus each of the four opaque bodies *P*, *A*, *B*, *C*, will give a double image on the sensitive layer. Knowing the distances *VV'*, *FF'* and those which separate each of the double images we can deduce from this the data for a precise localisation by graphical and numerical means. These data will enable us to regulate the compass so that its "sound" will lead the operator to the foreign body.

This is how we shall proceed practically. Having pre-

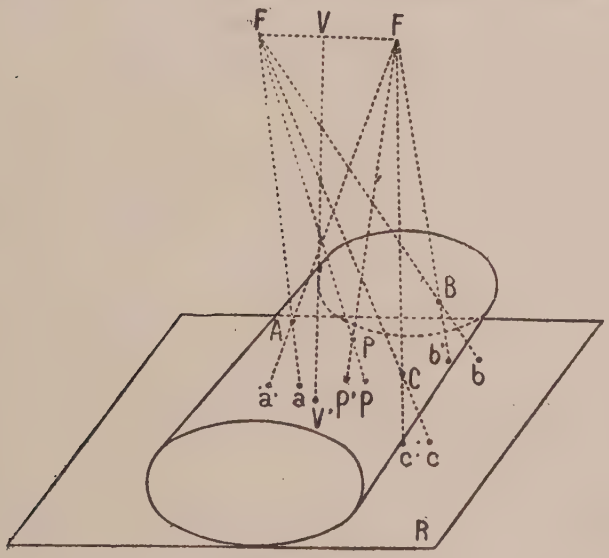


FIG. 158.

viously discovered the foreign body by a radiograph or screen examination and having settled on the surgical route of access after estimating its situation or its depth by a rapid process, we shall proceed as follows:

(*a*) Place on the table a plate of a convenient size enclosed in a paper envelope or in a cassette. The size 18 × 24 or 24 × 30 cm. will generally be sufficient if we use the Blondin tracing board.

(*b*) Fix in the middle of the envelope of the plate or of the cassette a small lead index (say of a triangular form).

(*c*) Centre the anticathode of the tube vertically over this index with the plumb-bob.

(*d*) Place the patient on the table without displacing the

plate or the tube in such a way that the point indicating the normal ray and passing through the projectile is directed less to the middle of the plate. The patient must be placed in the position for operation. (The centring stand of Charlier will be very useful for those doing this easily and correctly.)

(*e*) Select and mark three points on the skin. The triangle formed by them circumscribes the track of the normal ray. These points must not be either too near to each other, because in that case they would be much too near to the incision during the operation, or too far, because their image would then project outside the limits of the plate.*

(*f*) The tube is then placed at the desired height, say 60 cm. in every case. It is better to adopt a fixed distance to avoid error. Marks or stereoscopic wedges are placed on the horizontal tube carrier arm at 3 cm. from each side of the position of the tube.

(*g*) Two radiographs are taken on the same plate from two points of the space 6 cm. apart, determined by the markings of the horizontal arm just mentioned.

(*h*) After developing we notice on the plate a simple image for the triangular index, foot of the vertical, and of two conjugated images for the projectile and for each of the three marked balls.

(*i*) Mark the three cutaneous points (tattooing).

Interpretation of the Plate. Drawing the Graph.—(*a*) When the plate is dry mark with an ink spot the centres of the triangular index, the images of the marking balls and those of the foreign body.

* The tracing boards of Blondin greatly facilitate this placing in position on the plate. They consist of a series of frames traced on a rigid sheet of a transparent substance. The sheet is placed in contact with the skin, the borders kept parallel with those of the plate and the centre of the frames marked by a cross is brought directly under the plumb-bob denoting the vertical line from the anticathode. Those of the frames are chosen (they are made for varying heights differing by 5 cm. above the plate) which correspond to the thickness of the region.

It is then easy to make the localising marks on the skin. Under these conditions we are sure that the maximum sensitive surface will be used whilst the triangle formed by the markings will have the largest possible extent. On each marking point rests the lead ball which terminates the leg of the uprights supplied with each compass.

(*b*) Spread on the plate a sheet of transparent paper and copy the different points appearing on it. We obtain thus (Fig. 159) the points *O* (index), *pp'* (projectile), *aa'*, *bb'*, *cc'* (markings).

(*c*) Draw through the point *O* a parallel to the directions *aa'*, *bb'*, *cc'*, and mark *F* and *F'* at 3 cm. on each side of *O*. *F* and *F'* represent the horizontal projection of the anticathode in its two successive positions.

Join up in each group of the conjugated images the right image to the left focus and *vice versa* (for instance *b* to *F'* and *b'* to *F*). The intersections of these lines give the points 1, 2, 3 for the markings and *P* for the projectile, which are the horizontal projections we are trying to find.

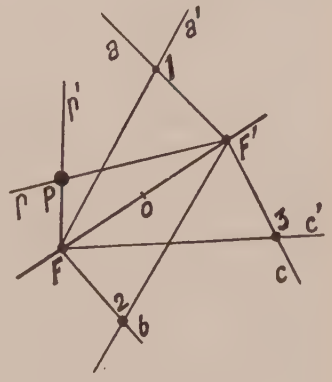


FIG. 159.

(*d*) Originally the method included the execution of another diagram giving the vertical projections of the different points in which we are interested (Fig. 160).

It is more convenient to use the simplified method described both by Henry Béclère and Morin and by Charlier which suppresses this second diagram. This method is as follows: Measure with a graduated ruler the distances *pp'*, *aa'*, *bb'*, *cc'*, which correspond to the distances between the conjugated images, and read off on a numerical table, previously made out and supplied by the manufacturer opposite the corresponding numbers the heights of the different points *P*, 1, 2, 3 above the horizontal plane (plane of the plate).

There is in existence a table calculated for the height of the anticathode of 60 cm. and another one for a height of 50 cm. It may also be replaced by a small graduated ruler supplied by the manufacturer which gives by direct reading the height of a point in terms of the distance between these two images.

(*e*) Deduct (algebraically) the number which expresses

the height of *P* (projectile) successively from those which correspond to the heights of the points 1, 2, 3 (markings). The differences are noted: they are those which will be used for the regulating of the compass for the depth.

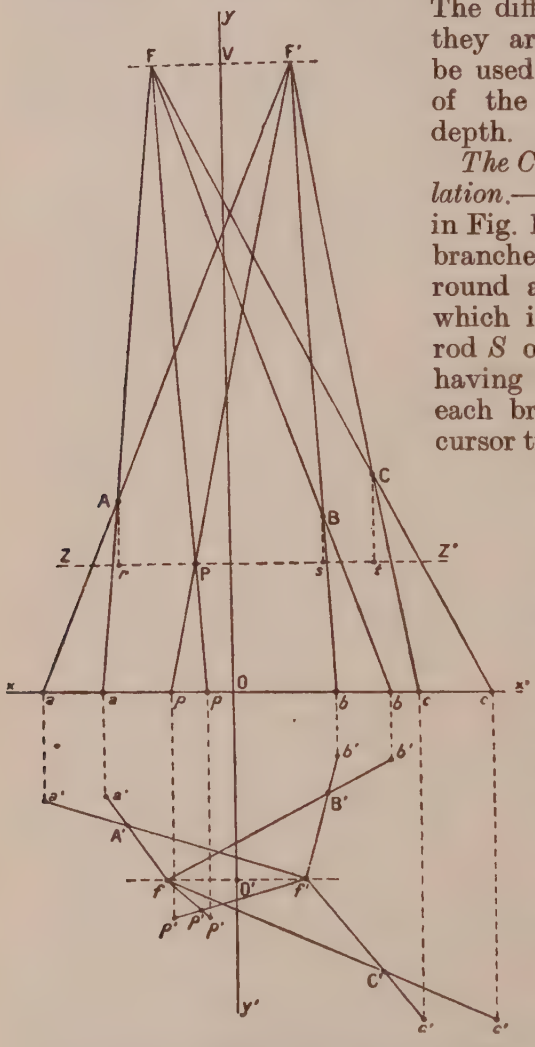


FIG. 160.—The Hirtz diagram, according to the first not simplified method.

The Compass and its Regulation.—The compass shown in Fig. 151 consists of three branches 1, 2, 3 turning round a common axis *O* in which is held by friction a rod *S* or a localising sound having fixed stop *r*. On each branch there glides a cursor traversed perpendicularly to the plane of the three branches by a rod on which is traced, starting from zero, a double graduation in millimeters. The cursors and their rods can be fixed in any position by binding screws. A thumb-nut placed at the lower part of the axis of the compass enable the branches to be fixed in a good position.

Round the axis of the compass there also turns an arc *d* on which also slides a cursor pierced by a hole in which the sound is held by friction. When the sound is in the central position it traverses the cursor of the arc and also the axis of the compass. If the cursor

is displaced on the arc the sound will take an inclined position *S'*.

Regulation of the Compass.—(*a*) Place the sound in a median position; bring the zero of each graduated rod flush with the upper surface of the corresponding cursor; unscrew the thumb-nut which frees the branches.

Depth Scale by MM. MORIN and Henri BÉCLÈRE.

Distance from centre of radiation..... 600 m/m.
Lateral displacement ..... 60 m/m.

Shift	Depth	Shift	Depth	Shift	Depth	Shift	Depth	Shift	Depth
m/m	m/m	m/m	m/m	m/m	m/m	m/m	m/m	m/m	m/m
1	10	11	93	21	155,5	31	204,5	41	243,5
1,5	14,5	11,5	96,5	21,5	158,5	31,5	206,5	41,5	245,5
2	19,5	12	100	22	161	32	208,5	42	247
2,5	24	12,5	103,5	22,5	163,5	32,5	211	42,5	249
3	28,5	13	107	23	166,5	33	213	43	250,5
3,5	33	13,5	110	23,5	169	33,5	215	43,5	252
4	37,5	14	113,5	24	171,5	34	217	44	254
4,5	42	14,5	117	24,5	174	34,5	219	44,5	255,5
5	46	15	120	25	176,5	35	221	45	257
5,5	50,5	15,5	123	25,5	179	35,5	223	45,5	258,5
6	54,5	16	126,5	26	181,5	36	225	46	260,5
6,5	58,5	16,5	129,5	26,5	184	36,5	227	46,5	262
7	62,5	17	132,5	27	186	37	229	47	263,5
7,5	66,5	17,5	135,5	27,5	188,5	37,5	230,5	47,5	265
8	70,5	18	138,5	28	191	38	232,5	48	266,5
8,5	74,5	18,5	141,5	28,5	193	38,5	234,5	48,5	268
9	78,5	19	144,5	29	195,5	39	236,5	49	269,5
9,5	82	19,5	147	29,5	198	39,5	238	49,5	271
10	85,5	20	150	30	200	40	240	50	272,5
10,5	89,5	20,5	153	30,5	202	40,5	242		

(*b*) Place the graph traced on transparent paper on a small drawing-board. Place the point of the localising sound-line on the horizontal projection *P* (Fig. 159) of the foreign body, then bring the extremities of each of the rods on the points 1, 2, 3; projections of the three marking balls; fix the binding screws of the cursors and the thumb-nut. In order to facilitate this regulating it would be convenient to use the special drawing pins invented by Chaperon. They are fixed on the points *P*, 1, 2, 3 and present notches which immediately stop the different rods of the compass in the correct position.

(*c*) In order to regulate the depth the three rods of the compass should be respectively shortened or lengthened by the number of millimeters found to represent the

difference between the height of each mark and the height of the projectile above the plate. The compass is then ready for the operation which is given in Chapter XIII.

The patient is brought into the operating theatre and placed on the table in the position in which he has been radiographed. This condition is not absolutely imperative ; because what we are trying to obtain is the concordance of the markings traced on the skin of the wounded with the extremities of the three rods of the compass. As soon as this condition has been brought about, the localisa-

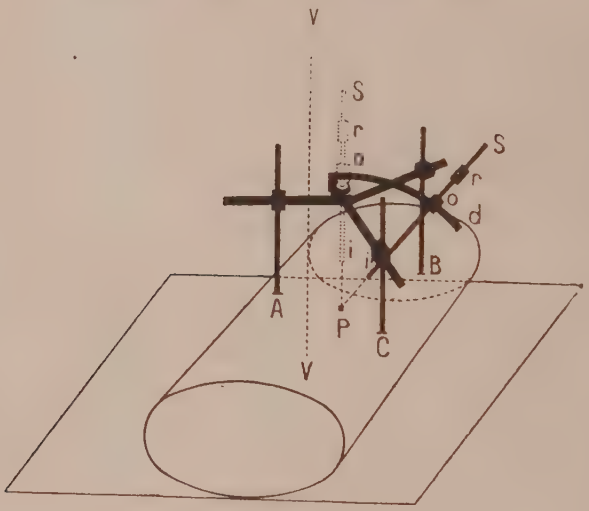


Fig. 161.

tion is correct and the localising sound lowered touches the skin at a point *i* (Figs. 161 and 162). The distance which separates the stop *r* from the upper surface of the cursor *o* indicates the depth of the foreign body. It will be necessary for the sound to penetrate the tissues to that depth so that its point may come into contact with the object we are looking for.

If for any reason the incision cannot be made at the point *i*, the sound is placed in a convenient oblique position by letting the cursor slide on the arc (Fig. 162). As this arc itself turns round the axis of the compass we can easily see that the sound can take instantaneously an

infinity of different positions, without having to make a new regulation. Still in all these positions its point will find the projectile because its length determined by the fixed abutment *r* is such that it represents exactly a ray of the circumference from which the arc has been taken.

The Compass includes two arcs, a short one (Fig. 163) and a long one (Fig. 162) which enable the sound to be deviated up to 90° from its vertical position of regulation.

The use of the arc has this essential peculiarity, an

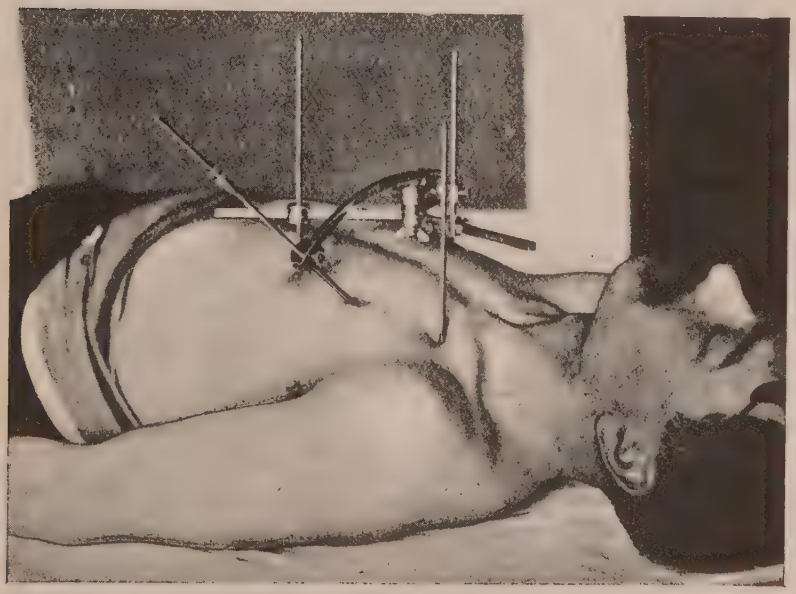


FIG. 162.—The Hirtz compass placed into position before the operation by utilising the large arc. (Plate by Dr. Henri Béclère.)

original characteristic of the Hirtz compass, in that it enables us to carry out the guiding on the lateral regions of the trunk, also to deviate from localisations made in an antero-posterior direction or inversely, and to leave the patient in a lying position.*

Used in its new and simplified form the localisation by the Hirtz method requires at an average from 30 to

* If we wish to use the compass with a tube placed under the table we use a special board called centring board.

40 minutes * and this time is greatly shortened if it is possible to undertake a series of localisations.

Nevertheless, we consider that this time taken is too long to enable this method to be generally adopted in its radiographic form in war radiology. Moreover, the plate obtained cannot generally be used from the radiodiagnostic standpoint.

FIG. 163.—The Hirtz compass and its little arc.

We therefore much prefer radioscopic localisations by means of any of the rapid processes already described, and the taking of a simple plate for diagnostic purposes only, if it is a difficult case. If however it is absolutely desired to have a radiographic localisation, we should use a process of two separated images, say one of those which supply stereoscopic images like the Richard processes, Paris, etc. (see Chapter X). The compass should be regulated according to these plates. Although it does not offer us the most perfect method of extraction (see Chapters XII,

* *Arch. Electr. Méd.*, March 1915, p. 110.

XIII, XIV) it is at least in our opinion, and in view of the absence of the possibility of using the intermittent control of the screen under good conditions, one of the best mechanical guiding instruments.

It seems to us moreover by far more practical to undertake its regulating exclusively by radioscopic means. The simplest form after having marked the three cutaneous marking points consists in measuring directly their distance from the plane of the table by means of a compass and in marking the projectile radioscopically. It is then easy to regulate the compass. This regulating gives then a precision within a few millimeters which in practice does not differ from the results obtained by the radiographic process in view of the multiple causes of error which always intervene and prevent that absolute precision which is theoretically possible.

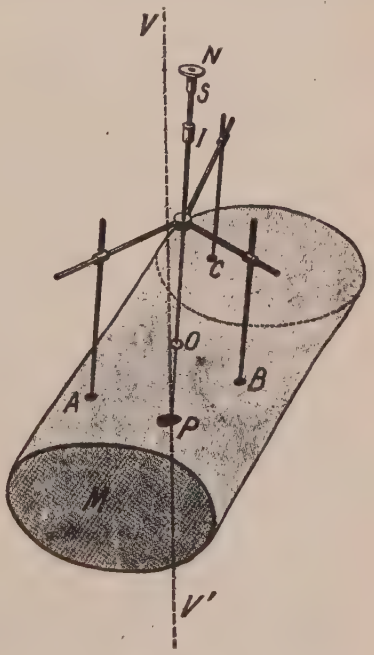


FIG. 164.

M. Hirtz has however himself described a process of regulating his compass radioscopically by means of his ingenious appliance of the pierced screen. The patient lies still in the position for operation, the projectile is localised, thereupon the extremity of the localising sound *S* of the compass is brought to the point *O* the exit of the normal ray marked previously at the moment of localisation (Fig. 164). The three points of the compass are placed on points *A*, *B*, *C* chosen, circumscribing *O* and in such a way that the direction of the sound *S* is practically vertical. The apparatus is thereupon mobilised by loosening the screw, until the spirit level of the sound shows that it is vertical and coincides consequently with

the normal ray. The screw is then made fast and the points *A*, *B*, *C* are definitely marked on the skin. As the depth of the projectile is known from the screen examination, the index *I* carried by the sound *S* is moved away from the centre *B* by a quantity *DI* equal to that depth, the regulating is then effected and the operation may be undertaken.

This process gives only the guidance for the vertical. In order to be able to use the arc it will be sufficient to shorten the length of each of the surrounding rods by a distance equal to the depth of the projectile.

Mr. Aimé uses the pierced screen in a somewhat different way by determining radioscopically the height of the ball-markers above the table and by regulating the compass on them as usual. He has introduced some slight modifications in the pierced screen of Hirtz-Gallot which still more facilitate its use for this regulation. Let us point out that the skiameter and bathymeter can be used perfectly well to regulate the Hirtz compass, a process which in our opinion will more and more supplant the radiographic method, in view of its suitability. We would therefore advise those who have to make use of that compass to have recourse to it.

After these detailed descriptions we can review the other appliances very rapidly.

*The Marion-Danion Marker.**—This instrument really consists of two parts; one part is a localising apparatus (proper) of the cross-wire type, of which the Mackenzie-Davidson type apparatus represents a practical and well-known form, reproduced almost identically by Messrs. Marion-Danion (compare Figs. 154 and 165); the other part is a "compass" added to this apparatus.

The marker gives the position of the projectile in relation to two marking points on the skin. It is regulated by means of two radiographs made on the same plate by materialising in space by two threads the two rays which supply the two projections of the projectile in the course

* See Marion, *The Localisation of Foreign Bodies with the Marion-Danion Localiser* (Paris, Maretheux, 1915); Marion, *Chirurgie de guerre* (Paris, Maloine, 1916); Weber, *Thèse de Paris* (1915); Charlier, "Le repéreur Marion-Danion" (*Journal de Radiologie*, 1915, p. 774).

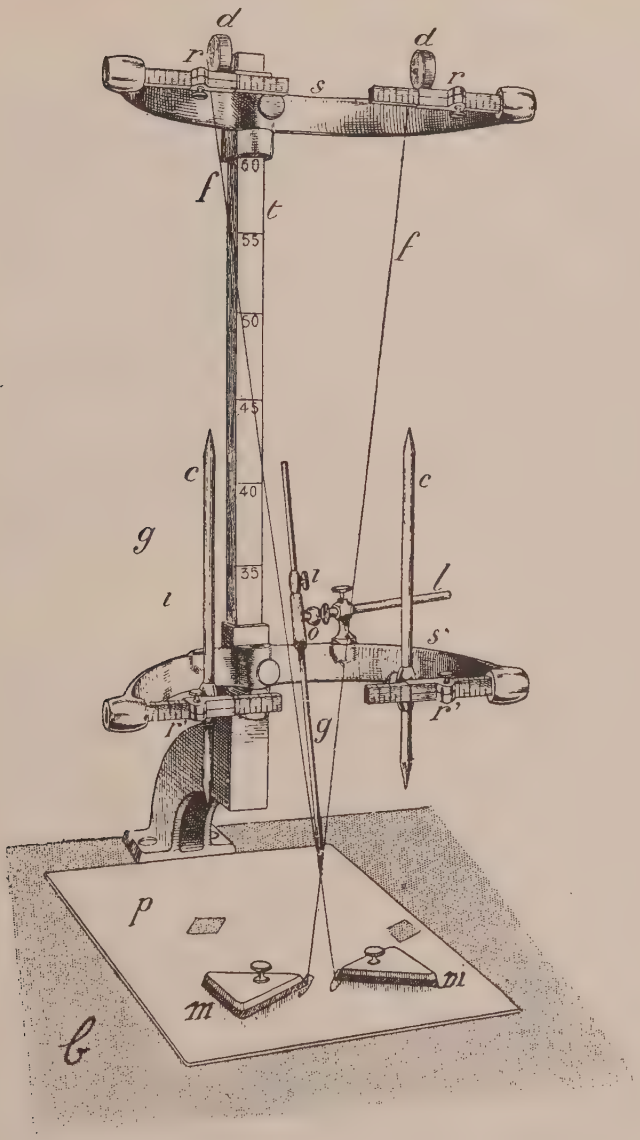


Fig. 165.—The Marion-Danion marker.

of two successive radiographs. It is then sufficient to bring the extremity of the indicating rod to the intersection

point of the two threads to enable the compass to be utilised.

This apparatus which can give excellent results when used by a good surgeon is very attractive owing to the facility with which its regulating can be understood. Its use is perhaps a little easier and less meticulous than that of Hirtz, but although it shares the other inconveniences of the latter it does not give the same facilities for operation (it has only two marking points and does not possess the large curved branch). It is cumbrous and expensive and does not seem to have come into general use. A similar simplified and much less expensive apparatus has been devised by Jallot.

The Aubourg Operation Indicator * (Gallot, manufacturer). —Being anxious to place at the disposal of radiologists an instrument which would enable them to ensure, whatever the radioscopic localisation method used, that the surgeon has a guiding rod during the operation, Aubourg designed at the beginning of the war an apparatus which materialises the path of the normal ray.

But as the surgeon wishes sometimes to have another way of access, this first apparatus has been modified with the collaboration of A. Lavialle, permitting the use of any route. It is possible with the aid of this instrument to introduce a curette or forceps into the wound and to obtain contact with the projectile. Figs. 166 and 167 give an idea as to the manner in which it is used.

In this respect we may point out that some authors have advocated, especially in England, the use of "operation indicators" regulated at the very moment of the operation carried out on the X-ray table, and which can be again regulated by radioscopic control during the operation. A somewhat similar appliance has been introduced in the ninth region by Mr. Maillard.

Owing to lack of space and to the fact that we have not or only insufficiently experimented with them we shall only mention other appliances such as those of Messrs. Loro, Buffon and Ozil, of Mr. Luzoir, of Mr. Masson (d'Oran), etc.

§ 42. **Localisation by means of a Tube with a Double Anticathode.**—It is evident that instead of using the two

* Lavialle, "Description technique de l'indicateur opératoire d'Aubourg" (*Journal de Radiologie*, 1916, p. 40).

shadows supplied by a displacement of the tube for

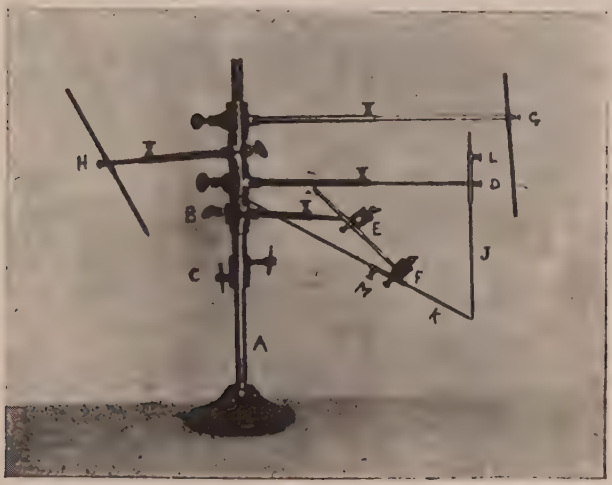


FIG. 166.—The Aubourg operation indicator with all its pieces for using either a vertical or oblique route of access.

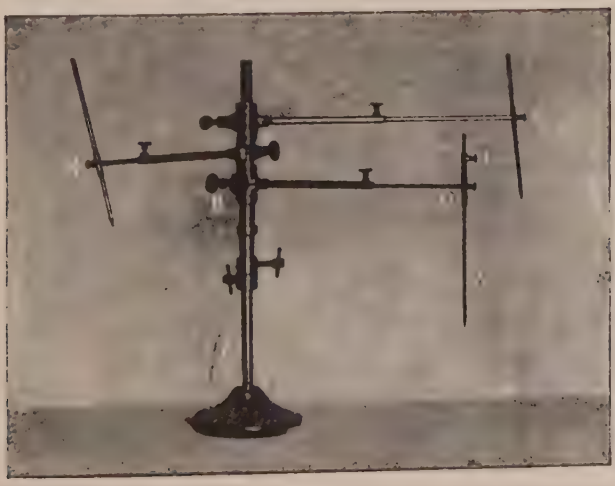


FIG. 167.—The Aubourg operation indicator with the pieces for using a vertical route of access only. (The pieces for the oblique access have been taken away.)

localising, it would be possible to make use of two different radiation sources from two different tubes.

The Mergier Process *.—This author seems to have been the first one to describe in 1898 this method. He used two Crookes tubes, the anticathodes of which were placed at a known distance from a fluorescent screen provided with an intersection of metal wires and worked by always using either radioscopically or radiographically the classical equation (p. 147).

The diagram in Fig. 168 which reproduces his apparatus from a figure which appeared in April 1898 in the journal *La Nature* is at first sight rather bewildering to those radiologists who did not go through those heroic times of radiology and they will have some difficulty in recognising the tubes. Mergier also invented a small ruler which made it possible after a very simple materialisation of the path of the rays to read the depth of the projectile directly, and avoid all calculation.

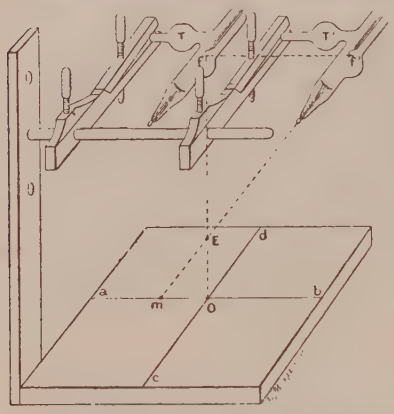


FIG. 168.—The Mergier appliance with two tubes.

In 1899 Warluz and Jollant† also used two distinct tubes and have since added to their method the use of a special compass.

These various authors made their two tubes work only in turn. Later on other experiment rs had the idea, in order to take the radiographs with a double pose, to let them start working simultaneously, so that the operation was shortened.

But the difficulties of exciting and regulating a second tube, whether included or not in the same circuit, did not make it possible to solve this problem in a practical way,

* "Mergier in Clerc," *La Nature*, April 30th, 1898.

† Warluz and Jollant, "Recherche des corps étrangers et des points visibles intéressants à l'intérieur des corps perméables aux rayons X Assoc. franc. pour l'Avance des Sciences" (Congrès de Boulogne-sur-Mer, 1899).

and led the experimenters to the conception of a single tube containing two foci : the tube with a double anticathode. Introduced at first in France by Guilloz (Fig. 169), this new type was soon imitated in Germany and an instrument which is now used by our enemies for the determination of the depth of projectiles has been based on its use. This instrument is based on the following considerations. The distance from the two sources (generally the displacement of the tube, here the distance between the two anticathodes) being invariable and known (say 6 cm.) the distance anticathode—screen (or plate) also being invariable and known (say 60 cm.) it is, as we have seen, extremely easy to know the distance from the screen—or from the plate—to the projectile by a simple measurement of the distance between the two images. It is therefore easy to design an instrument of a type of a compass with a double opening, constructed say (Fig. 171) in such a way that by measuring between the points A and B the distance between the two homologous points of the two shadows of the projectile we can read in front of the index I carried by the branch BD, on a graduation inscribed on an arc of the circle EH carried by the branch AC, directly in millimeters, the distance from the projectile to the plate (or to the screen).

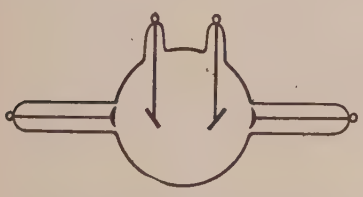


FIG. 169.—Tube with a double anticathode by Guilloz.

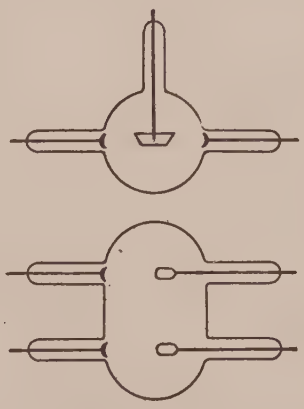


FIG. 170.—Two types of tubes with double anticathode.

In spite of its undeniable convenience the use of tubes with a double anticathode has not become popular in view of the difficulties of their construction, of the usual

asymmetry in the working of the two anticathodes and of their rapid heating.

This abandonment of a type of tube which lent itself to multiple and interesting applications, not only from the standpoint of localising projectiles, but also from the radio-stereoscopic standpoint, has induced one of us with Dauvillier to interest M. Pilon in this direction. Fig. 172 shows this remarkable tube with a double anticathode, water cooled, which he was able to construct and we shall explain later on how we have applied it to the localisation and extraction of projectiles.

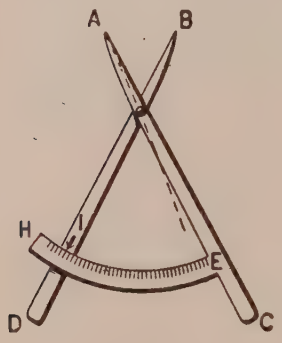


FIG. 171.

§ 43. **Practical Conclusions.**—In order to make our choice with advantage from the rather numerous methods already described by us or mentioned in this and in the preceding chapter, and from the large number which we had to omit either through lack of space or of sufficient documents to be quite familiar with them, it is necessary to consider carefully the object aimed at, the material at our disposal and especially the process of extraction which will be adopted.

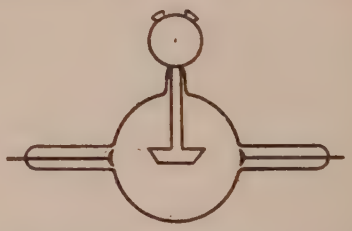


FIG. 172.—Diagram of a tube with double anticathode by Ledoux-Lebard and Dauvillier (Pilon, manufacturer).

Localisation by the method of two axes which intersect has the advantage of being simple, economical and rapid, but very often it lacks precision, and consequently cannot be used in a general way. This can only be used for projectiles of limbs which are to be removed by means of the intermittent control of the screen, or in cases of emergency in certain front line units. We think that it is infinitely preferable to choose, amongst the radioscopic methods based on the displacement of the tube, one of those which are really applicable to all possible cases and which more-

over offer, as compared with radiographic processes, considerable advantages of convenience, rapidity and of quite sufficient precision, and in all cases to use the same method of localisation. But according to the region, to the difficulty or to the peculiarity of the case the operator should provide himself with all the necessary information by taking one or more plates, and by using all the necessary complementary examinations. These plates will supply data which will be clearer and more useful than localisation plates by double exposure, which generally have no diagnostic value.

The Haret method which is very simple and which may be applied in all cases and does not necessitate any complicated calculation is greatly to be recommended. The same applies to the process of the pierced screen by Hirtz-Gallot, which is simple, rapid and may be used anywhere (except on board a ship). These processes require only a minimum of special material. Among those which demand a costlier outfit though very slightly more complicated we personally give the preference to the Viallet-Dauvillier method modified by Dessane (Radiobathymeter), as constantly used by one of us in the service at Tours. It is simple, rapid and precise and can be used for all projectiles which can be removed surgically.

With these methods the surgeon who undertakes the extraction aided by the intermittent control of the screen and guided by a professional physician-radiologist is sure to obtain good results. They will also enable the radiologists to regulate their apparatus simply and rapidly when they are working for surgeons who are not in possession of this resource through not having the appropriate apparatus or who use it only as a check, but work with a compass, or finally for those who persist in their method of working and use a mechanical guiding instrument exclusively.

Finally to those who wish to remain absolutely true to radiography alone either from habit or from a fear of cutaneous accidents (a fear which is only justifiable when the radiologist already suffers from marked chronic affection of the skin), or from lack of anatomical and medico-surgical knowledge which does not enable them to use radioscopy without misleading the surgeon, we recommend

DEPTH-SCALE WORKED OUT

GIVING THE DEPTH, THE DISTANCE ANTICATHODE TO SCREEN

COEFFICIENTS

DISTANCES ANTICATHODE — SCREEN

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
38	3,8	7,6	11,4	15,2	19,0	22,8	26,6	30,4	34,2	38,0	41,8	45,6	49,4	53,2	57	60,8
39	3,9	7,8	11,7	15,6	19,5	23,4	27,3	31,2	35,1	39,0	42,9	46,8	50,7	54,6	58,5	62,4
40	4,0	8,0	12,0	16,0	20,0	24,0	28,0	32,0	36,0	40,0	44,0	48,0	52,0	56,0	60	64
41	4,1	8,2	12,3	16,4	20,5	24,6	28,7	32,8	36,9	41,0	45,1	49,2	53,3	57,3	61,5	65,6
42	4,2	8,4	12,6	16,8	21,0	25,2	29,4	33,6	37,8	42,0	46,2	50,4	54,6	58,7	63	67,2
43	4,3	8,6	12,9	17,2	21,5	25,8	30,1	34,4	38,7	43,0	47,3	51,6	55,9	60,2	64,5	68,8
44	4,4	8,8	13,2	17,6	22,0	26,4	30,8	35,2	39,6	44,0	48,4	52,8	57,2	61,6	66	70,4
45	4,5	9,0	13,5	18,0	22,5	27,0	31,5	36,0	40,5	45,0	49,5	54,0	58,5	63,0	67,5	72
46	4,6	9,2	13,8	18,4	23,0	27,6	32,2	36,8	41,4	46,0	50,6	55,2	59,8	64,4	69	73,6
47	4,7	9,4	14,1	18,8	23,5	28,2	32,9	37,6	42,3	47,0	51,7	56,4	61,1	65,8	70,5	75,2
48	4,8	9,6	14,4	19,2	24,0	28,8	33,6	38,4	43,2	48,0	52,8	57,6	62,4	67,2	72	76,9
49	4,9	9,8	14,7	19,6	24,5	29,4	34,3	39,2	44,1	49,0	53,9	58,8	63,7	68,6	73,5	78,4
50	5,0	10,0	15,0	20,0	25,0	30,0	35,0	40,0	45,0	50,0	55,0	60,0	65,0	70,0	75	80
51	5,1	10,2	15,3	20,4	25,5	30,6	35,7	40,8	45,9	51,0	56,1	61,2	66,3	71,4	76,5	81,6
52	5,2	10,4	15,6	20,8	26,0	31,2	36,4	41,6	46,8	52,0	57,2	62,4	67,7	72,8	78	83,2
53	5,3	10,6	15,9	21,2	26,5	31,8	37,1	42,4	47,7	53,0	58,3	63,6	68,9	74,2	79,5	84,8
54	5,4	10,8	16,2	21,6	27,0	32,4	37,8	43,2	48,6	54,0	59,4	64,8	70,2	75,6	81	86,4
55	5,5	11,0	16,5	22,0	27,5	33,0	38,5	44,0	49,5	55,0	60,5	66,0	71,5	77,0	82,5	88
56	5,6	11,2	16,8	22,4	28,0	33,6	39,2	44,8	50,4	56,0	61,6	67,2	72,8	78,4	84	89,6
57	5,7	11,4	17,1	22,8	28,5	34,2	39,9	45,6	51,3	57,0	62,7	68,4	74,1	79,8	85,5	91,2
58	5,8	11,6	17,4	23,2	29,0	34,8	40,6	46,4	52,2	58,0	63,8	69,6	75,4	81,2	87	92,8
59	5,9	11,8	17,7	23,6	29,5	35,4	41,3	47,2	53,1	59,0	64,9	70,8	76,7	82,6	88,5	94,4
60	6,0	12,0	18,0	24,0	30,0	36,0	42,0	48,0	54,0	60,0	66,0	72,0	78,0	84,0	90	96
61	6,1	12,2	18,3	24,4	30,5	36,6	42,7	48,8	54,9	61,0	67,1	73,2	79,3	85,4	91,5	97,6
62	6,2	12,4	18,6	24,8	31,0	37,2	43,4	49,6	55,8	62,0	68,2	74,4	80,6	86,8	93	99,2
63	6,3	12,6	18,9	25,2	31,5	37,8	44,1	50,4	56,7	63,0	69,3	75,6	81,9	88,2	94,5	101
64	6,4	12,8	19,2	25,6	32,0	38,4	44,8	51,2	57,7	64,0	70,4	76,8	83,2	89,6	96	102,5
65	6,5	13,0	19,5	26,0	32,5	39,0	45,5	52,0	58,5	65,0	71,5	78,0	84,5	91,0	97,5	104
66	6,6	13,2	19,8	28,4	33,0	39,6	46,2	52,8	59,4	66,0	72,6	79,2	85,8	92,4	99	105,5

This table, primarily intended for use with the skiameter, can also be used with the image, including the radioscopic

AND THE COEFFICIENT OF MAZÉRÈS SCALE BEING KNOWN.

COEFFICIENTS

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
38	64,5	68,5	72	76	80	83,5	87,5	91	95	99	102,5	106	110	114	118	121,5	125,5
39	66,2	70,2	74	78	82	85,7	89,5	94	97,5	101,5	105	109	113	117	121	124,5	129
40	68	72	76	80	84	88	92	96	100	104	108	112	116	120	124	128	132
41	69,7	74	78	82	86	90	94	98,5	102,5	106,5	110,5	115	119	123	127	131	135
42	71,4	75,5	80	84	88	92	96,5	101	105	109	113	117,5	122	126	130	134	138,5
43	73,1	77,5	81,5	86	90,2	94,5	99	103	107,5	112	116	120	125	129	133	137,5	142
44	74,8	79,2	83,5	88	92,5	97	101	105,5	110	114	119	123	127,5	132	136	140,5	145
45	76,5	81	85,5	90	94,5	99	103,5	108	112,5	117	121,5	126	130,5	135	139,5	144	148,5
46	78,2	83	87,5	92	96,5	101	106	110	115	120	124	129	133,5	138	142,5	147	152
47	80	84,5	89	94	98,7	103,5	108	113	117,5	122	127	131,5	136,5	141	145,5	150	155
48	81,5	86,5	91	96	100,6	105,5	110	115	120	125	129,5	134,5	139	144	149	153,5	158,5
49	83,2	88,2	93	98	103	108	112,5	118	122,5	127	132	137	142	147	152	157	162
50	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165
51	86,7	92	97	102	107	112	117	122,5	127	132,5	137,5	143	148	153	158	163	168
52	88,3	93,5	99	104	109	114,5	119,5	125	130	135	140	145,5	151	156	161	166	172
53	90	95,5	100,5	106	111	116,5	122	127	132,5	138	143	148	154	159	164	169,5	175
54	91,8	97	102,5	108	113	119	124	130	135	140	146	151	156,5	162	167	172,5	178
55	93,5	99	104,5	110	115	121	126,5	132	137,5	143	148,5	154	159,5	165	170,5	176	181,5
56	95,2	101	106,5	112	117,5	123	129	134,5	140	145,5	151	157	162,5	168	173,5	179	185
57	97	102,5	108	114	119,5	125,5	131	137	142,5	148	154	160	165,5	171	177	182	188
58	98,5	104,5	110	116	122	127,5	133,5	139	145	151	156,5	162,5	168	174	180	185,5	191,5
59	100,5	106	112	118	124	130	136	142	147,5	153,5	159	165	171	177	183	188,5	195
60	102	108	114	120	126	132	138	144	150	156	162	168	174	180	186	192	198
61	103,6	110	116	122	128	134	140	146	152,5	158,5	164,5	171	177	183	189	195	201
62	105,5	111,5	118	124	130	136	142,5	149	155	161	167	173,5	180	186	192	198	205
63	107	113,5	120	126	132	138,5	145	151	157,5	164	170	176	183	189	195	201	208
64	109	115	121,5	128	134	141	147	154	160	166,5	173	179	185,5	192	198	204	211
65	110,5	117	123,5	130	136,5	143	149,5	156	162,5	169	175	182	188,5	195	202	208	214
66	112	119	125,5	132	138,5	145	152	158,5	165	172	178	185	191,5	198	204	211	218

bathymeter and for all radioscopic procedures depending on the displacement of the regulation of the compass.

any of the methods with exposures on two different plates (see Chapter X).

As a mechanical guiding instrument we recommend preferably the Hirtz compass without however wishing to in any way detract from the merits of other instruments.

Finally for especially difficult cases in which the localisation of the projectile in relation to the bone may be difficult and plays an important part in the choice of the way of access as well as in the success, rapidity and facility of operations the Belot method should be used.

It must not be forgotten however that the best method is always the one which we know best.

After making the localisation of a projectile we must note the results obtained as well as the position of the patient when it was done. Special forms are very useful for this purpose. Those used by us are of a different colour (blue) from the ordinary radiographic forms (white); at the top they have a frame containing general indications similar to those reproduced in the form on p. 126, and at the bottom the particulars given on p. 234, taken partially from the form made out by Viallet in the fourth region.

We reproduce on the previous page the Dauvillier ready-reckoner which is useful for all processes of localisation which use the method of the double image, and especially for radioscopic methods as well as the skiameter and bathymeter.

RADIOLOGICAL LOCALISATION FORMS

A shrapnel bullet
A rifle bullet
A shell fragment (approximate dimensions:)
is lodged in the $\frac{\text{soft}}{\text{osseous}}$ parts under the $\frac{\text{right}}{\text{left}}$ surface of:

A point has been marked on the skin. The projectile is situated at millimeters below that point.

The position of the wounded during the radioscopic localisation:
Ventral
Dorsal
Left lateral.

The decubitus was right lateral.
Indication of accessory positions:
Particular remarks:
Result of Operation: Operated upon at
by Mr.

Of course this form may be easily modified as desired according to the process used.

CHAPTER X

RADIO-STEREOSCOPY

§ 44. It is only natural that the idea should be entertained of applying to radiography the very attractive advantages of stereoscopy. Messrs. Imbert & Bertin Sans (of Montpellier) appear to have been the first to make practical application of this principle in March 1896, whilst Messrs. Marie & Ribaut endeavoured to determine geometrically the rules of accurate radio-stereoscopy in accordance with the data established by Cazes in a series of highly interesting memoirs. They have shown how they thought it possible to measure distances by means of stereoscopic radiography and have published the description of a stereometer.

Since their time nearly every radiologist interested in this branch of the science has added something to the technique and has proclaimed its advantages. We need only mention the works of Messrs. Aubourg & Galezoski and of M. Béclère in France and also those of Sir James Mackenzie-Davidson in England. In spite of the justifiable enthusiasm felt by every radiologist for the incomparable beauty of stereoscopic reproductions, it does not appear that the art has been developed in this country to the extent it deserves. At a time when in the United States it was being applied almost systematically to every radiographic examination, the art of stereoscopy was still during the period before the war in its infancy in France ; since then however, it has not escaped being rediscovered by a certain number of neophytes, who, without the knowledge of previous research and of the theoretical and practical objections to which it is susceptible, desired to apply it indiscriminately to the localisation of all foreign bodies.

We cannot think of explaining here, however briefly, the theory of stereoscopic vision, and we must refer those who desire to study the subject to the works already mentioned. We will content ourselves with pointing out that the essential principle of binocular vision is that of the perception of relief experienced when each eye receives an image (and a different image) of the same object. The appreciation of relief and of distances between objects depends upon the psychical interpretation of two different luminous impressions based upon education and habit.

Generally speaking, the problem of stereoscopic photography and radiography lies chiefly in obtaining two images of the object, or set of objects, which are to be reproduced in relief, each image corresponding to that of one eye. If arrangements are made, so that the image corresponding to the right eye is clearly seen by that eye, and the image corresponding to the left eye by the other eye, then the sensation experienced is that of appreciation of relief in those persons who possess stereoscopic vision, and although

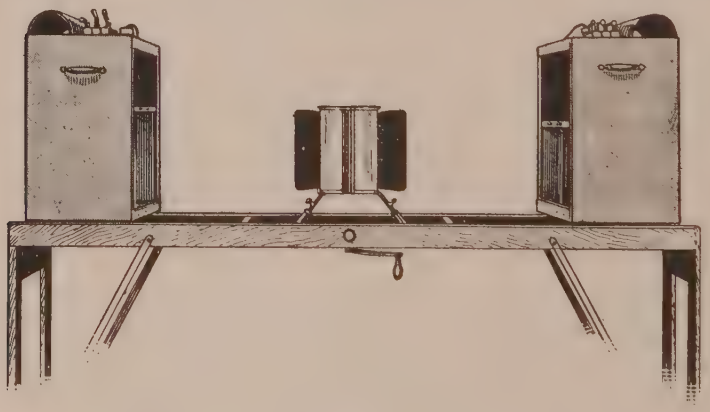


FIG. 173.—Wheatstone Stereoscope.

the two images are dissimilar and not capable of being superimposed one on the other, they will still give the impression of one single object.

Inventors have therefore devoted themselves to the exact reproduction of these retinal images.

In order to obtain these images photographers use two cameras coupled together and provided with identical lenses, the main axes of which are parallel; the distance between the two lenses corresponds in general to the mean distance between the eyes, that is to say 7 centimeters. By using one camera only, which can be moved to a distance of 7 centimeters in a horizontal line perpendicular to its main axis, one would evidently obtain the same result.

A similar process is observed in stereoscopic radiography, but, instead of a lens, in this case a tube is employed. By moving this tube to the right and to the left in succession two images, *i.e.* radiographs, are obtained, viz. a right and left image.

However, this displacement of the tube the distance required and the changing of the plate, which must be executed without causing the slightest movement of the portion radiographed (the change being always perpendicular to its main axis), is a delicate operation which takes the operator some time to effect. It has therefore been proposed to construct foot levers to displace the tube automatically after the first exposure and also to arrange frames provided with an automatic release and with a changing device which will simultaneously substitute the second negative for the first. Americans, especially Lester Leonard Case and Pfahler, have been able to obtain by these technical means marvellous stereoscopic radiographs of the viscera, the two exposures and all details of which have been carried out within a total period of one to two seconds at the most.

With the object of simplifying this work and doing away with the necessity of displacement of the tube and replacing it by a change of connections, use has also been made of double anticathodal tubes, which we have already mentioned in the previous chapter. However, their use has, so far, not become general on account of certain technical difficulties attending their construction.

In order to examine the two negatives obtained, so as to give the impression of relief, they should be viewed either by means of the Wheatstone stereoscope (Fig. 173), or the stereoscope by M. Hírtz (Fig. 174); or, if time is no object, reductions can be made, which can then be

simply examined by means of one of the small hand stereoscopes described as "Mexican." These are highly to be recommended, as they are not only easy to operate but are also very inexpensive.

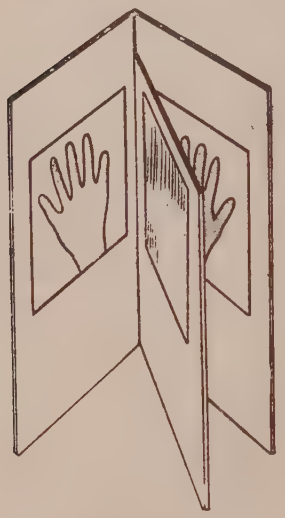


FIG. 174.—Hirtz Stereoscope.

In some cases stereoscopes of the type introduced by the Canadian radiologist Pirie are employed. In appearance and size they resemble pocket binoculars, and permit of a direct examination of two stereoscopic radiographs placed next to each other on the same plane (Fig. 175). A French model of that instrument, the *Mattey stereo-telescope*, was presented by Aubourg to the Radiological Society.

In all these cases the contrast is obtained just as if the eye were substituted for the tube, the right eye in the position of the right tube and the left eye in the position of the left tube respectively. This contrast is called *direct* or *orthoscopic*. If the respective position of the negatives be changed, and the negatives taken in the left position of the tube be observed with the right eye, and the right negative with the left eye, then we obtain the impression that the object has been reversed in relation to the observer, the relief being described as *reversed* or *pseudoscopic*. For instance, if it is a question of a stereoscopic radiograph of the hand, the palmar surface facing the observer, we shall see it from its dorsal aspect on reversing the position of the negatives. This pseudoscopic examination may have a certain interest, particularly in the search for foreign bodies; and, if it be easy to effect it by means of this simple transposition of the radiographs in the case of

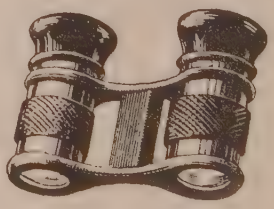


FIG. 175.—Pirie Stereoscope.

separate negatives, it is none the less easy when taking the two images on the same plate or paper, the one image being consequently superimposed upon the other. In this connection Messrs. J. Richard & Colardeau have invented an ingenious stereoscopic device (Fig. 176) which permits the examination of radiographs at will, either with ordinary relief or with pseudoscopic relief, by simply changing the eyepieces used.

There is no need to insist upon the fact that the whole interest of stereoscopic radiography lies in the search for

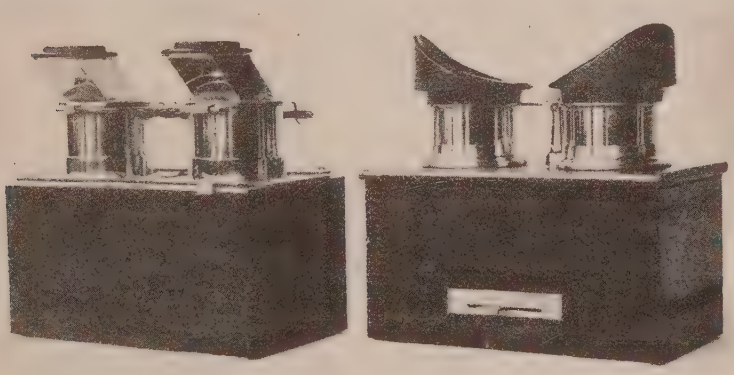


FIG. 176.—Orthoscopic and pseudoscopic stereoscopes by Richard and Colardeau giving the impression of contrast by direct examination of the negatives without reduction (the pseudoscopic apparatus is on the left).

and extraction of projectiles. An examination of stereoscopic negatives shows at once, for instance, whether the projectile lies in front of, behind or within the neck of the femur, giving at the same time an admirable view of the concomitant bony lesions, fractures, loss of substance or osteo-periostitic proliferations, etc. This enables one to obtain most important data, and it is frequently possible to obtain a topographical localisation of the projectile so that it can be treated with success surgically. For this reason stereoscopic radiography represents a useful addition to those various methods of localising projectiles which have already been spoken of, as well as to radioscopic examinations for anatomical

localisation which are dealt with in the next chapter. In certain examinations of the skull, face, shoulder or hip—if a perfect representation is required—it may prove to be almost indispensable to ascertain the exact position of the projectile in relation to the bony image before doing anything else. In every case the images obtained are distinguished by their plastic effect, and by the facility with which they enable one to form an image in space.

Not content with these results, which are sufficiently remarkable in themselves, the most enthusiastic experts have for some time past asserted that they can employ this method for the most varied and precise measurements, and that they can apply this *stereometry* to determine the position and depth of projectiles.

In order to achieve this result the first essential factor is to obtain images yielding an absolutely true reproduction of the actual state of affairs. For this purpose Messrs. Marie & Ribaut, taking as their basis Caze's studies on the geometry of lenses coupled together, have formulated rules enabling them to establish a method which they term the *precision method.*

We shall only make mention here of their classic formula according to which, in order to obtain exact results, it is necessary to formulate the following equation by which—

$$\triangle \text{ max.} = \frac{D\,(D\,P)}{50\,P}$$

in which $\triangle$ is the maximum distance between the two foci, (in this case the two positions of the focus of the anticathode), P the maximum thickness of the object to be radiographed, and D the distance between the tube and the object.

It may be mentioned that this point of view has not been endorsed by all authors, M. Destot in particular having made some very adverse and apparently not unreasonable criticisms ; and, without availing themselves of the formula already mentioned, most radiologists are content to adopt in all cases a fixed distance between the two positions of the tube, viz. : 6 centimeters, 6·5 cm., or 7 cm., and they are perfectly satisfied with this method of procedure.

Whatever position may be adopted with regard to this

question, which we cannot now discuss at greater length, Messrs. Marie & Ribaut have continued and extended their studies, and were the first to describe a *stereometer* for radiological purposes. But the few works devoted to this art of mensuration had been quite forgotten until research work, in connection with war projectiles, gave it a fresh interest and caused more numerous investigations to be carried out in that direction. Under the name of "Tauleigne-Mazo's *radiostereometer* a new apparatus has been introduced, the technical construction of which has been simplified, in

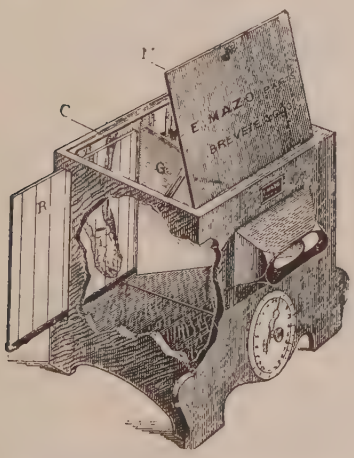


FIG. 177. — Radiostereometer. View of the whole. In the bottom part *R*, the lined net which slides in front of the stereoscopic negative *C* can be seen. The micrometer is shown in front. (By Mazo.)

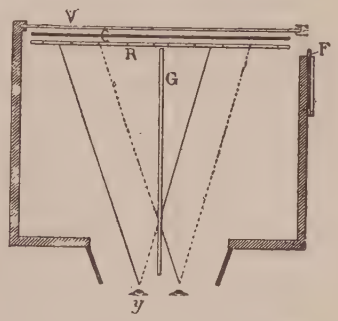


FIG. 178.—Horizontal section of the radiostereometer. *V* is a ground glass; *C* the negative; *R* the lined net; *G* the double-faced glass; *y* shows the place for eyes. It will be observed that according to whether the observer looks to the left (complete lines) or to the right (dotted lines) the impression of orthoscopic or pseudoscopic relief will be obtained, according as the image observed by each eye happens to be the direct image or the image seen in the glass of the corresponding negative. (By Mazo.)

as much as it makes an ingenious use of the net system — first applied by M. Béclère to the stereoscopic measurement of depth.

The stereoscopic images are taken under exactly the same conditions as regards adjustment of the tube and the distance between the two foci (4 centimeters between the two successive positions of the anticathode) and they

are taken on the same negative. The latter is placed in the apparatus shown in Fig. 177. The sketch 178 shows a sectional elevation thereof, and enables one to understand the respective arrangement of the negative *C*, of the glass *R* (bearing a net of parallel vertical lines), and of the double mirrors so that the observer, according as to whether he looks to the right or to the left, will have the impression of true, or pseudoscopic relief.

Once the sensation of contrast has been obtained the displacement of the lined net, and the reading of the micrometer, indicate the depth of the projectile.

The firm of Jules Richard has constructed an "instantaneous metrical gauge" which shows, by direct reading, the depth of a projectile from the stereoradiographic negative, and we consider it to be one of the best apparatus of its kind now in existence.

This apparatus consists of a rectangular frame, for receiving the negative, which is kept in position by means of clamps. Slides and guides permit of the displacement of pointers which are fixed at two symmetrical places on each of the images formed by the projectile. By the simultaneous adjustment of the graduated scales the reading shows the depth of the projectile in millimeters.

Another apparatus by the same constructor, the stereothesimeter by Messrs. Paris & Richard (Fig. 179), permits of the determination not only of the exact depth of any chosen point on a stereoscopic negative, but also of defining its length and breadth; that is to say of ascertaining without calculation the three co-ordinates of that point. A "stereoradiographic scale," Chauvelon-Richard system, has also been introduced by the same firm.

It must, however, be pointed out that on the whole there is no longer any question of stereoscopy in the strict sense of the word, as far as these various processes are concerned. Two negatives are used which are obtained by displacing the tube, exactly in the same way as by the radiographic process of the double image, dealt with in the preceding chapter. It is found that these negatives also possess the property of being stereoscopic, but we no longer have any need to resort to that property to determine the depth of the projectile.

In consequence of the fact that a sufficiently large

number of persons, estimated by various authors at 10% or 20% do not possess stereoscopic vision, we are inevitably compelled to adopt this course, and to abandon in the strict sense of the word stereoscopic localisation, when trying to obtain the great advantage of possessing images which give an impression of contrast (when localising by the double-image radiographic methods). For a method of this kind this is a latent defect which needs to be remedied. Considering, furthermore, that the normal sense of vision brings also the psychic faculties into play, stereoscopic vision possesses a subjective side, which it is difficult to reconcile with the requirements of a method of

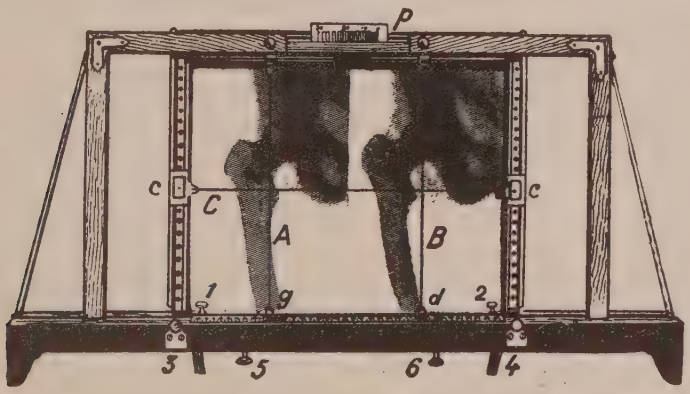


FIG. 179.—View of the Paris-Richard " stereothesimeter."

measurement which must essentially be objective. In fact, comparison of the readings of the depth of a projectile, by means of a real radio-stereometric apparatus such for instance as that by Tauleignemazo, obtained by different observers, very rarely gives figures which agree in a satisfactory manner.

Every radiologist should therefore know and utilise stereoscopic radiography in all cases where it seems advisable, because the information provided will frequently be of just as great value to him as to the surgeon when desirous of *locating anatomically* (in relation to the skeleton) the position of a projectile ; or for completing and determining the data given by two rectangular radiographs, or above all it is of still greater value for this purpose in certain regions, and more especially in the region of the

head, the shoulder and the pelvis. On the other hand, stereo-radiometry properly so-called does not appear to deserve recommendation, at least as far as the general method for the localisation of projectiles is concerned.

But all those who persevere in the use of radiographic localisation methods, by the double-image process, will be more and more inclined to replace the single double-exposure negative by two stereoscopic images taken on the same plate. In this way they can the more easily succeed in arranging their pointers, and they will have negatives which can be used both from the radio-diagnostic and anatomical localisation point of view.

Stereoscopic radioscopy belongs to the future. We shall only devote a few lines to explaining its principles by reason of its great interest which is at present more theoretical than practical.

After having applied the principles of stereoscopy to radiographic images, endeavours were soon made to extend them also to radioscopic images. If two sources of X-rays at a slight distance apart (6 to 10 centimeters) be utilised as foci for illuminating the fluorescent screen, and if the shadows projected upon that screen by a body placed between it and the X-ray sources (by arranging a system of shutters so as alternately to shut off in turn one eye and one source) be examined in this manner, the object will apparently be viewed in relief. If one eye and the source of the rays at the *opposite* side be simultaneously uncovered, then the impression obtained is that of true relief; whilst, if one eye and the source at the same side be uncovered at the same time, then it will be noticed that the impression is one of pseudoscopic relief.

Messrs. Roullies & Lacroix, followed by Guilloz, and especially Villard, have invented extremely ingenious devices for the utilisation of this method, but they are still too complicated and more especially require too delicate adjustment to enable them to be of any practical value.

The cross-wire method when applied to stereoscopic radioscopy has not had any greater success, and this very attractive method has so far not been allowed to emerge from the sphere of the laboratory nor is one able to

obtain contrast effects on the screen for any other than very simple and transparent objects and such parts of the body as the hand and forearm.

It is therefore not surprising that its application to the study of projectiles has not yet been the subject of any work during the course of this war; at least not so far as we are aware.

However, having studied the works previously published on that subject, it occurred to one of us and to A. Dauvillier * that it might be interesting to apply the special facilities presented by the double anticathodal tube to ascertain the relative depths of two objects, such as for instance a projectile and the end of a pair of forceps, in order to obtain *radioscopic* data as to depth which would be of some use to the surgeon in connection with his work. In fact, it is known (see Chapters XIII and XIV) that, in order to effect extraction of foreign bodies by means of intermittent control of the screen, the surgeon must be able to operate by following the direction of the normal ray. When he cannot look for the projectile by searching directly downwards in this way, following the true direction of a straight line perpendicular to the plane of the table, he loses the elements of *absolute security* and rapidity offered by that method. On approaching the projectile obliquely, it may happen that the instrument is either above or below, thus necessitating a great waste of time in groping about for the object, and he may even be obliged to abandon extraction altogether when operating in a difficult and dangerous part, owing to not having an exact idea as to the position of the projectile in relation to the route by which it entered. Even if the tube be moved about in order to observe the relative displacements of the shadows of the projectile on the one hand, and the end of the forceps for instance on the other, and thus to determine their respective depths (according to the indications given for localisation by the so-called "knife method," p. 177), nevertheless the exact relationship may be very difficult if not impossible to determine.

We will now consider a double anticathodal tube. It

* R. Ledoux-Lebard and A. Dauvillier, "New Radioscopic Method for accurately determining the Situation of Foreign Bodies during Surgical Procedure" (*C.R., Ac. Sc.*, t. 161, p. 575).

produces on the fluorescent screen two shadows of the same opaque point, symmetrically placed in relation to the normal plane taken in the middle of the straight line which connects the foci (Fig. 180). Assuming A and A' to be the central ray of each focus, P a projectile lying anywhere within the body S of a subject placed on the operating table T, we shall perceive on the fluorescent screen E two images, P' and P'', of the projectile. If we introduce into the tissues an instrument, I, in order to determine its relationship to P, then the point of the instrument will give two shadows, I' and I'', which will only coincide with P' and P'' if P is in the same plane as I. On endeavouring to make the shadows coincide, we shall of necessity come across the objects which produced them. On the other hand, it is evident that when the forceps are between the projectile and the screen, that is to say at a lesser depth than the latter, the distance $I'\ I''$ will be less than $P'\ P''$, and consequently if the forceps were between the tube and the projectile, that is to say deeper than the latter, then the distance $I'\ I''$ would be greater than $P'\ P''$.

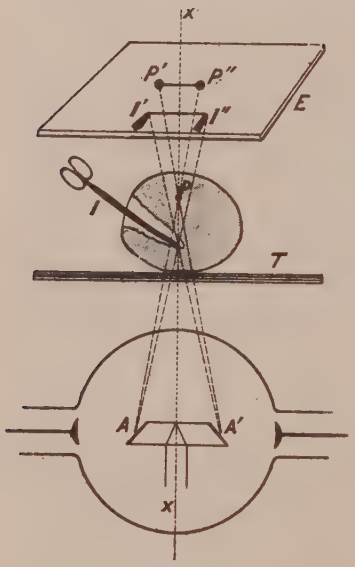


FIG. 180.—Use of the double anticathode tube. Assuming P to represent the projectile included in the part of the body S examined on table T by means of a tube possessing two anticathodes A and A', we shall have on the fluorescent screen E two images, P' and P'', of said projectile. If we introduce, to locate it in the tissues, an instrument I, we shall have on the screen two images I' and I'', of the end of that instrument, and the distance $I'\ I''$ will be greater than $P'\ P''$ if the point of the instrument be at a greater distance from the screen—in other words *deeper* in the tissues—than the projectile.

Particularly in the extraction of pulmonary projectiles by the method of M. Petit de la Villeon (see Chapter XIV),

it seems that this kind of intermittent control of the screen ought to afford very great facilities for seizing the projectile with the least possible probing and injury to the tissues. We have been able to satisfy ourselves of its value in this and other instances.

However, there are two difficulties in practice which become the more acute the thicker the part which is being dealt with.

The first difficulty is that every projection due to an anticathode is veiled by the other, to such an extent that it is only possible to obtain on the screen two very faint shadows which immediately become invisible when a difficult region is under observation. In order to obtain an adequate image it is necessary to employ a diaphragm which avoids this, and which, at the same time, allows the two shadows to be seen just as dark and sharp as if each of them had been obtained in the ordinary way. This is very easy to arrange.*

The second, but much greater difficulty, is two-fold—firstly that experienced in obtaining double anticathodal tubes which are capable of adequately resisting heavy current, and secondly the difficulty of pairing them. In fact this obstacle, and the impossibility encountered by German constructors in manufacturing symmetrical tubes of this type capable of being kept sufficiently cool, have stopped the development of radiological work in this respect, thus largely preventing the extension of stereoscopic radioscopy.

* For that purpose a diaphragm is mounted above the shield with a rectangular aperture *D*, made of two lead shutters operated by a pinion engaging two racked bars, so that the opening can be changed in a lateral direction. This moves in a vertical direction along a slide-bar, and is so arranged that the centre of its aperture is always on the vertical *XX'*, which is the symmetrical axis of the tube. Having effected this adjustment the method of seeking and finding the foreign body in the radioscopic field is effected as follows:

The screen *E* being fixed above the body of the subject, the diaphragm is opened very wide and fixed on a level so that the two illuminated regions, which appear on the screen, almost coincide. The foreign body is then searched for in the ordinary way and, when located, the tube is so moved that the two shadows are adjusted symmetrically with respect to the black line separating the two illuminated regions. The opening of the diaphragm can then be reduced so as to increase the clearness of the shadows.

In spite of the present difficulties one of us has been fortunate enough to succeed, in conjunction with Mr. A. Dauvillier, in having manufactured by M. Pilon, according to fresh plans, a double anticathodal *water-cooled* tube, *which can be placed equally well under the radiological table* as on a tube stand ; this tube can easily withstand 2 milliampères per anticathode with penetrating rays and is of perfect symmetry. Although the considerable difficulties of manufacture which constitutes a real triumph in producing a tube which German industry has been unable to produce, seem to prevent its being made commercially *at present*, the problem has nevertheless been solved in a practical manner, and we believe that its application will become more general in future (see § 42). The Coolidge double anticathode tube will, doubtless, finally be manufactured in this form, not only for this kind of simplified stereoscopy (or, to be more exact, the transition method between localisation by displacement of the tube and true stereoscopy), but also for *stereoscopic radioscopy*, which is also a very attractive subject.*

* With regard to the whole of this chapter it will be interesting to read the recent work by Sir James Mackenzie-Davidson, *Localisation by X-rays and Stereoscopy* (London, 1916).

CHAPTER XI

ANATOMICAL LOCALISATION

§ 45. After having determined the presence of a projectile and its exact depth from a given point on the skin, the work of the radiologist for the surgeon is not by any means completed. It is, in general, much more important for the surgeon (for the sake of safety, promptness, and success in his operation) to know the *anatomical site* of a projectile rather than its exact depth in millimeters.

It is, for instance, of much less importance for the operator to know that a metal fragment is lodged in the thorax at a depth of 32 or 38 millimeters, than to be certain whether it is intra-pulmonary or not. That a shrapnel bullet has its site 61 or 71 millimeters deep at a level with the lumbar spine is of much less interest than the knowledge as to whether it is within the body of the vertebra or in the surrounding tissues.

However, it certainly seems that this point of view is not generally shared by all radiologists, perhaps because certain surgeons do not always sufficiently realise the extent of the information in this respect which they can demand and obtain; and also because some radiologists, being neither medical men nor anatomists, are unable to give them correct particulars. Now it is precisely here that the *absolute necessity* is felt that the radiologist should have a knowledge of anatomy and possess a sound medico-surgical education.

The sad consequences of neglecting to determine the anatomical site of the projectile to be located become manifest by studying works already published concerning the extraction of projectiles. The following observation is frequently met with therein: "The operation commenced was abandoned owing to the injuries it might

have caused." It is therefore evident that the surgeon who knows the topographical site of a projectile will be well aware of the anatomical difficulties he will have to overcome, and he will not be ignorant of the injuries his interference may cause. If he undertakes it on these conditions, that is to say with full knowledge, he will have no other valid reasons for interrupting it excepting in the one case the impossibility of finding the projectile, or perhaps the subject is a bad one for anæsthesia, or an anatomic difficulty impossible to foresee and exceedingly rare, such as a vascular anomaly, an arteriovenous aneurism, or, finally, an operative accident, such as opening a large vessel in the course of the search. We are of opinion that the fear of injury is too often claimed in order to conceal a failure.

The utility of anatomical localisation has, besides, been recognised and already noted by many radiologists. MM. Arcelin, Belot, Brocq, Robineau, Viallet, amongst others, have frequently insisted upon its necessity, and have indicated (with regard to various parts of the body) how it was possible in most cases to arrive at precise data of very great importance to the surgeon, by making use of the various resources of radiological science. M. Zimmern endeavoured to find an easy solution to the various problems involved by publishing a series of sections of the body and limbs ; once the depth has been ascertained, it is sufficient to refer to these, in order to determine the exact anatomical seat of the projectile. The anatomical sections, and especially the collection of those by Doyen, may certainly be of some service and it will be useful to consult them occasionally. However, they are possibly only of real assistance in difficult cases. In fact, it is evident that anatomical conditions vary too much between one case and another by reason of the thickness of the soft parts (fat, muscles, etc.), and also on account of the great degrees of difference in the dimensions of the various parts of the skeleton. It will therefore be impossible to adhere exactly to the data supplied, and so they lose all their importance so far as the practical point of view is concerned, and that alone is of interest here.

Whilst making a summary in this chapter, we shall see,

that if radioscopy is practised by making use of that elementary knowledge of anatomy and physiology which every medical man ought to possess, the position of the projectile can nearly always be indicated in a topographical manner. This *anatomo-clinical* localisation, to use Viallet's expression, is still possible in those cases in which the object is not found by screening in various positions, or by taking two radiographs at right angles to each other, or by stereoscopic radiographs, or by localising methods such as those of Belot, Hirtz, etc., in relation to the skeleton.

Sometimes it is necessary in order to obtain quickly important information and to avoid gross blunders, to practise active or passive movements of the region to be examined, bearing in mind the classical principles of physiology. The patient can be made to perform certain movements, the operator then can palpate him under the screen and mobilfse him by the aid of some rigid instrument.

Let us bear in mind that it has been possible, by examining both from the back and front, to diagnose quickly to which side the projectile is nearest; that the exact localisation of the depth has been effected; that the position on the skin of the normal ray passing through the projectile has been precisely determined (called by Viallet surface localisation), and that *one* negative and perhaps *two negatives at right angles* or a stereoscopic image in the case of a difficult projectile have been, or will be, taken. Finally, if the situation of a projectile is to be determined in relationship to certain muscles, then the screen examination can be employed with advantage.

We shall now briefly consider the problem for each particular region of the body, describing only some of the chief points in connection with each. Every one will easily be able, with a little practice, to complete for himself those details which must necessarily be omitted by reason of the limited scope of this work.

§ 46. **Head and Neck.**—(1) *The Skull.*—As to the skull, two examinations (by screen or negatives) at right angles to each other, generally furnish sufficiently precise data as to the exact seat of the projectile. With respect to certain regions, such as the temporal fossa in particular,

attention will, however, have to be paid to a cause of error (due to the special configuration of the skull) which may cause projectiles, really situated outside the cranial cavity, to be regarded as intra-osseous or intra-cranial.

The following diagram shows that a projectile situated

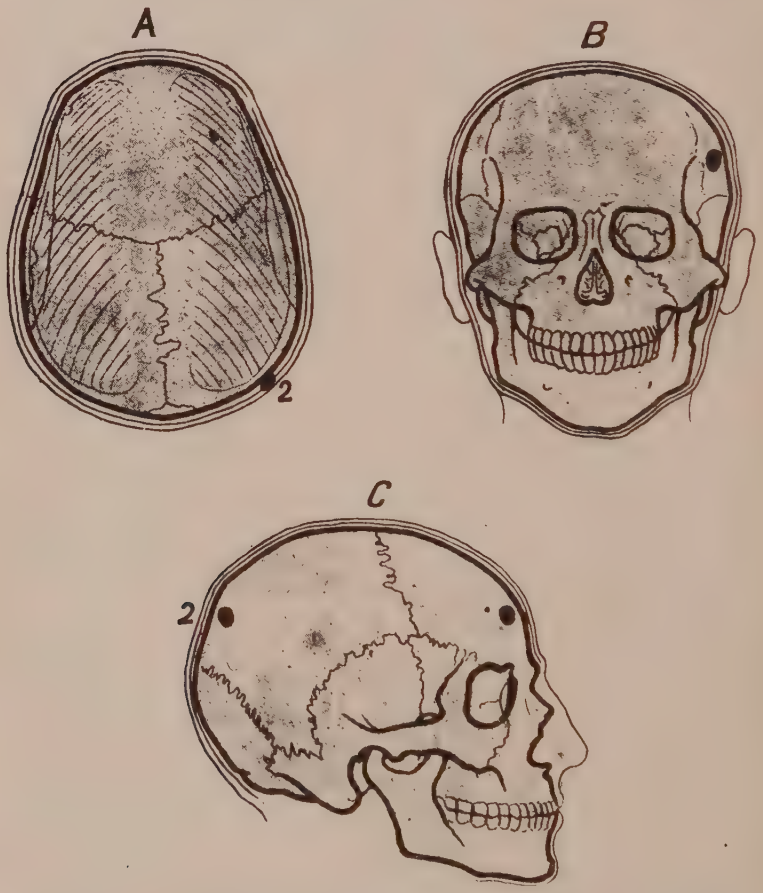


FIG. 181.—The horizontal section *A* of the skull shows how a projectile situated at 1 or 2 outside the skull, but in the soft parts, will nevertheless cause its shadow to appear to be inside the skull as seen at 1, figure *B*, in a postero-anterior or antero-posterior radiograph. In the lateral view (see figure *C*) these projectiles also appear to be situated in the interior of the skull. In these cases therefore the two radiographs taken at right angles to each other lead to an erroneous conclusion as to the seat of the projectile.

at 1 (figure *A*) will appear to be situated within the skull in a radiograph taken in the antero-posterior direction.

A radiograph in a third direction would then be required for purposes of verification, for instance one taken through the *vertex* towards the roof of the mouth or in the opposite direction. Besides, in these cases a radioscopic examination executed with a little care will obviate any mistake, because by turning the head of the patient a position will be obtained at which the projectile will be seen to be extra-cranial. Stereoscopic radiography will also enable one to obtain useful information.

(2) *Face.*—Stereoscopic radiography will frequently have to be made use of for examination of the cavities of the face without which topographical localisation of the projectiles is often difficult as has been proved by us by various examples and researches made in collaboration with Dr. Hautant.

As regards the maxillary bones, negatives should be taken in accordance with the procedure adopted in dental radiography following the Belot method.

(3) *Eye.*—The examination and localisation of projectiles in the orbit constitute absolutely a special chapter of our subject. In the first place the eye is the only organ in which one has to take into account the possibility of removal, and therefore the localisation of metal particles sufficiently small as to be hardly visible is a matter of great importance. The procedure is therefore so delicate a matter that it ought to be reserved for specialists. For this reason we shall not discuss here the question of war ophthalmology, as one of us will shortly devote an extensive volume to this subject in conjunction with A. Terrien.

We shall content ourselves with mentioning that in order to know whether a projectile in the neighbourhood of the orbit is intra-ocular, a question which may occasionally have to be solved by any radiologist, and the solution of which may have very great importance as regards the permanent sight of the wounded, the following procedure should be adopted.

The exposure of the negative is commenced with the patient looking upwards. It is interrupted for a moment and then continued whilst the patient looks downwards.

Except in rare cases in which the projectile occupies the centre of the eyeball itself, a double image of the projectile will be obtained on the negative if the foreign body is situated in the interior of the eye at any other point than at its centre or in the muscles, because in this method if the head is kept absolutely motionless only the eyeball will have moved.

The remarks made by our colleague Terrien on the importance of immediate removal of these projectiles, and on the use of large electro-magnets and of small magnets for this purpose, forms so special a subject in ophthalmology that it cannot be dealt with further here.

(4) *The Neck.*—It is very rare for the radiologist not to succeed in determining the exact situation of a projectile in the neck, if a lateral and an antero-posterior view is obtained and the depth is known; this is a point of great importance in extraction as, owing to the extreme mobility of the head and neck, the least obliquity is important.

In the case of the larynx, as in the œsophagus, a lateral view should be obtained with a soft tube, and the patient should be made to carry out the movements of swallowing; —in this way any projectile in this situation will be observed to move and the position can then be noted either in the semi-oblique or lateral view, as one of us has been able to observe in conjunction with Hautant.

Sometimes it is a good plan to make the patient eat bismuth tablets or bismuth milk, in accordance with the usual methods of radiological examination of the œsophagus.

§ 47. **The Thorax.**—The exact localisation here is of great importance and can be rapidly and accurately carried out in a properly conducted radiological examination, and at the same time other conditions such as pulmonary abscess, pleurisy, etc., may be revealed—a point of great importance to the surgeon in view of what decision is to be made.

As well as conducting an examination in this case, as in other parts of the body, with the patient in the operation position, it is important also to examine him vertically behind the screen, turning him in every direction.

The first question arises as to whether the projectile is nearer the front or the back. The difference in the size

of the shadows in the two situations will clearly enlighten us, unless it is situated almost exactly half-way between the two, a fact which can be determined in a lateral view. If situated laterally we can determine whether it is purely parietal and extra-thoracic by turning the patient obliquely so as to cause the shadow to appear outside the costal margin (Fig. 28). But when it is very near the middle line of the body either in front or at the back, examination of the profile may not be absolutely conclusive and may be difficult. Besides, the projectile may be contained in a rib (Fig. 1, Plate V), between two ribs, or immediately underneath a rib and yet extra-pulmonary. Upon placing the subject in the position in which the shadow is clearest, we can cause him to breathe deeply and slowly, and so by careful observation on the screen we can then determine whether or no the shadow moves with breathing.

This will not be *absolutely* impossible unless it is on the middle line or near same and close to the back wall. The measure of the depth and the indispensable profile negative will then enable us to obtain complete certainty (see *Spine*).

If it is only very slightly movable, rising at inspiration and descending at expiration, the projectile is most likely parietal. Let us fix on the skin near it a small piece of lead by means of an adhesive. We shall then see if the shadow of the projectile and that of the mark exhibit the same amount of movement. This rise on inspiration is, besides, a little more marked in front than at the back and attains its maximum at the sides.

At the level of the bases projectiles are sometimes observed lying free in the pleural cavity, being either present in an effusion or having fallen into the pleura in the course of an extraction. These projectiles, which hardly move at all on respiration, nearly always go to the most slanting part with the patient's movements.

It is, moreover much more frequent to see them fixed in the costo-diaphragmatic groove either in consequence of the resorption of fluid or directly through adhesive pleurisy. They are then almost motionless with respiration, but when examined at a proper angle and with *forced inspiration* if the diaphragm is not completely im-

mobilised by adhesions, it will be found that they stand out quite clearly against the rest of the lung.

Projectiles should not be considered to be actually within the lung unless on radiographical examination very extensive respiratory displacement is noticed. This is correct in all cases of projectiles situated below the hilus, or in the lower lobe, as these exhibit the greater mobility the nearer they are to the diaphragm, so that they follow its movements exactly to its full extent when they are very near to it. It will therefore evidently be necessary to examine these projectiles in the condition of apnœa if useful information is desired.

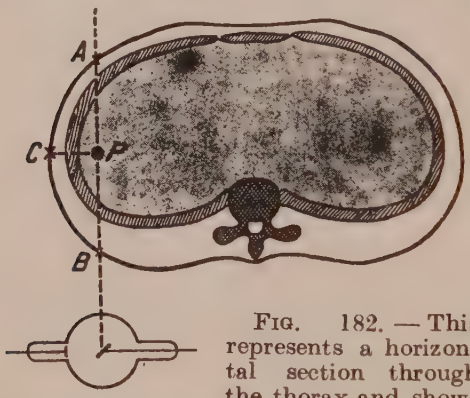


FIG. 182. — This represents a horizontal section through the thorax and shows us that a projectile, *P*, located at 12 centimeters from the posterior wall and 10 centimeters from the anterior wall, for example, may quite likely only be 4 centimeters distant from a point on the lateral wall of the thorax. It will therefore always be necessary, before making the localisation, to ascertain the approximate site of the projectile in relation to the lateral wall and to make sure that it does not afford a better way of access.

On the other hand, projectiles of the upper lobe and of the right middle lobe or of the postero - superior part of the lower left lobe are little or very little affected by respiration. In the middle, the centre of respiratory immobility, they may even be quite immobile. This fact also should not be forgotten, namely that they follow besides in these cases the pulmonary movements of coughing.

Examination in various directions must take into account the necessary orientation for finding the nearest way of access. The diagram (Fig. 182) shows that a projectile, *P*, may have been localised at 10 centimeters, for instance, from the anterior wall, but may be quite near the lateral wall. The radiologist should always draw the

attention of the surgeon to this fact for his own guidance, but he will of course choose the most suitable way for himself.

It need not be pointed out that the radiologist must take notice of the condition of the lungs during his examination and take into consideration the presence of any abscesses, patches of opacity, condition of pneumothorax, diseased glands, tuberculous lesions, traces of pleurisy, pulmonary scars, which may indicate the path of the projectile (Belot), and, above all, the presence or absence of pleural adhesions, all this information being important as regards the question of operation.

*Calcifications.**—We have already mentioned in Chapter V the errors of diagnosis so often caused by the presence of glands caused by pulmonary or pleural calcifications which stand out very sharply in the clearness of the pulmonary field and easily lead to confusion with a projectile; and this is especially the case in radioscopy. In all doubtful cases the operator should proceed as we have indicated, placing near the suspected body a metal body and comparing the two shadows radioscopically and radiographically. By following this course he will generally succeed in suspecting the calcareous nature of the shadow seen which is almost always less dense than the shadow of a metal fragment (aluminium alone excepted).

The most frequent of these calcifications are evidently those of glands in the trachea, bronchus, and mediastinum which are very often pulsatory in character, but the anatomical distribution of these should cause him to suspect their nature. But calcareous concretions of various forms—pulmonary stones or thin plates—are often met with all over the lungs. A position near the hilus must not therefore necessarily be supposed to be due to a projectile. We have in this manner removed a calcareous plate from the lower lobe, and one of us has also extracted, with Gosset, a concretion of the size of a large pea which was almost sub-cortical, and, with Dr. Gandar, a large stone together with a shell splinter, the stone having been in close proximity to it.

Pulsatory Projectiles.—Even without breathing many

* See also the interesting article by Albert-Weil in the *Paris médicale.*

thoracic, pulmonary, or mediastinal projectiles—especially near the middle line—are very difficult to locate on account of the pulsation transmitted to them by the beating of the heart and aorta. Besides, this pulsation may often, no doubt by reason of the elasticity of the pulmonary tissue, be communicated to a great distance and one will find projectiles pulsating very far from the middle line in the right half of the chest or away from the heart in the left half of the chest. We have already mentioned a few pages back (a fact known to all radiologists) that the same kind of pulsation is frequently observed in cases of tracheo-bronchitic glands and various interpulmonary calcifications. We must also mention in passing the existence of pulsatory pleurisies.

Foreign Bodies in the Trachea and Bronchi.—The diagnosis of the intratracheal or intrabronchial site of a projectile cannot be made with certainty unless a special movement on coughing is observed. But as a matter of fact, this is a rare site for projectiles, and personally we have only come across one case of this kind. The subject had a small intrapulmonary splinter and he was operated on by M. Robineau during an intermittent screen examination. In the course of the examination the patient had a fit of coughing, after which the projectile was seen no more on the screen, but a more complete examination showed it to be in the other lung. It was expectorated afterwards.

But if projectiles situated in the trachea and bronchus are rare, the frequency with which foreign bodies, especially nails, are swallowed by accident, in children is well known.

We do not wish to discuss these cases here at length because of the number of considerations which would lead us outside our subject. We shall content ourselves regarding this subject with referring to the recent remarkable work by Chevalier Jackson and with mentioning that extraction of foreign bodies from the bronchi is greatly assisted by a screen examination in two positions.

The Heart and Pericardium.—Projectiles are often observed to be lying free in cases of pericardial effusion; they are then movable and fall towards the most dependent point on altering position of the patient. When they are fixed in a localised pericardial effusion the question of possible aneurism must be considered.

PLATE IV.

FIG. 1.—Side view of a radiograph of the skull as seen from the right side. The shadow of a whole bullet from a German rifle will be noticed the point of which is directed backwards and downwards towards a level which corresponds approximately to that of the body of the corpus callosum. A little above the projectile is a small shadow, less dense, due to a sequestrum.

FIG. 2.—Front view of a radiograph of the skull. The shape of the bullet at this angle should be noticed. The shadow is seen approximately exactly in the middle line. In this negative will be noticed the *frontal sinus*, *the frontal-parietal suture*, *and occipital suture*, which is especially clear, and the trace of a trephine hole caused by a first attempt at extraction. By making use of this opening the bullet was easily extracted by means of an electro-magnet.

Radiographs of the skull, particularly side views, furnish, it should be noted, first-rate data for *the anatomical localisation of cranial lesions*, thus providing the surgeon with topographical information of the greatest importance.

Unfortunately we cannot deal with this very interesting question here, even very briefly, as it would lead us outside our province.

We shall content ourselves with drawing the attention of radiologists to the use of the set of diagrams for the localisation of cranial lesions published by Pierre Marie, Foix and Bertrand (Paris, Masson & Co., publishers). These can be drawn on tracing paper and then placed upon the negatives, in which manner they can be used to great advantage in all laboratories of radiology.

PLATE IV

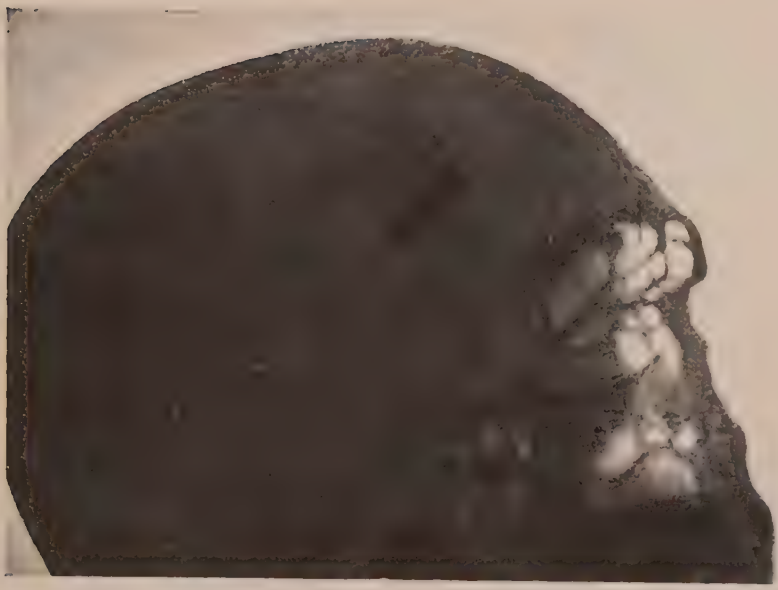


FIG. 1

FIG. 2

As to projectiles actually in the heart, they are not so rare as might be thought, and we have come across about ten of such cases.

Among these cases there must be distinguished in the first place those properly described as intracardiac, *i.e.* those lying free in the cavities, in which they are free to move like a pill in a box (see Plate VII).

As to those embedded in the walls, their diagnosis is often difficult. It must be ascertained by an examination carried out in different positions that in no position is the shadow of the projectile dissociated from that of the heart (see Fig. 2, Plate VII). Thus a positive result can be obtained for the apex and the left half of the heart, but a mis ake may be made at the base if the projectile is in one of the cardiac (coronary) grooves or between the large vessels.

From the radiographic point of view it should be noted that good negatives will only be obtained by means of instantaneous exposure (see R. Ledoux-Lebard, *Journal de Radiologie*, 1916).

§ 48. **Diaphragm.**—We shall devote a special paragraph to projectiles in the region of the diaphragm, whether intra-thoracic or intra-abdominal, because to the radiologist of experience and understanding they lend themselves to easy topographical deductions which are of special value to the surgeon, but they very often cause unqualified specialists to make mistakes, which are unfortunately shared by the operator.

A projectile, which in a front view of the patient is seen in the shadow of the diaphragm like the bullet *P* in the diagram (Fig. 183), may really (as is shown in Fig. 184, which shows the side view of same) be either in the space between the lung and diaphragm or within the thickness of the diaphragm itself, that is to say it may be still in the abdomen (and, in that case, either below the diaphragm or intra-hepatic in the example which we have chosen). In all three cases the projectile will present very marked respiratory movements of almost identical amplitude. How shall we make the differential diagnosis of the exact position ?

In order to ascertain whether it is within the lung we can make the patient breathe deeply and try in this

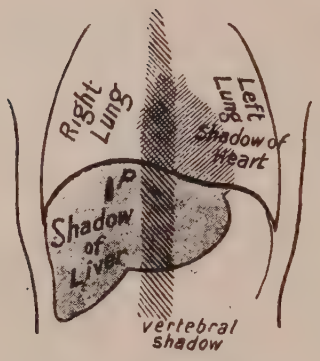


FIG. 183.—Diaphragmatic region seen from the front. The projectile *P* is shown in the hepatic shadow, under the right dome of the diaphragm.

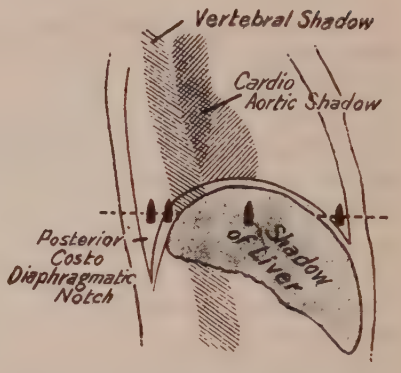


FIG. 184.—Diaphragmatic region seen from the right side. Observe the different situations in which the projectile may be, as shown in *P* in the preceding figure.

manner to cause the projectile to be seen—wholly or partly—in the pulmonary clearness when the dome of the diaphragm descends. Fig. 185 shows us the appearances seen from the front in the usual examination.

FIG. 185.—The figures 1, 2, 3 respectively indicate the position of the diaphragm at expiration, at average inspiration, and at forced inspiration. It can be seen that the projectile *P*, first hidden in the shadow of the liver, under the dome of the diaphragm, will first show its point and then appear entirely in the pulmonary clearness, thus revealing its seat in the lung.

It is evident that radioscopic or radiographic examination in the lateral position will give us the best information, but it will sometimes happen (owing to weak installations, thick subjects, etc.) that this method of examination is impossible or very difficult. The diaphragm, even in forced inspiration, will not show up the projectile in an examination conducted from the front without any other precaution.* We should then

* It is interesting, in some cases, to cause the diaphragm to contract greatly on one or both sides by the faradisation of one or two phrenic nerves.

remember what we have already said in Chapter III about employing oblique rays. The figure will, in fact, show us for instance that by raising our tube and making use of oblique rays we shall see a bullet, hidden in the costo-diaphragmatic space, quite clearly on the screen.

In cases of sub-diaphragmatic projectiles we must essentially have recourse to the method of lateral and oblique examinations, making use sometimes of various methods (bismuth meals or enemata), and especially insufflation of air in the large intestine or distention of the stomach with gas. In the absence of these methods the knowledge of the point where the shadow of the projectile is projected on the surface of the body, coupled with estimation of depth and the clinical examination, allows a fair notion as to position to be obtained, but is not always exact.

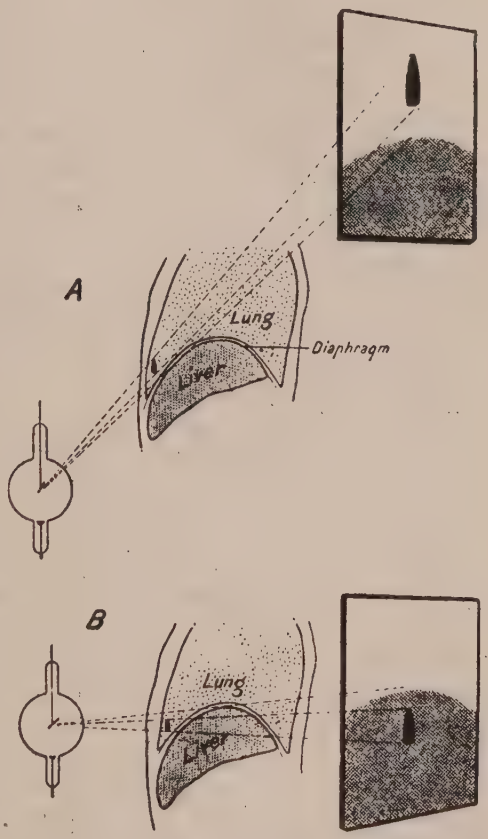


FIG. 186.—The diagram *A* shows us how an examination with oblique rays reveals the presence of a projectile in the lung by causing it to appear in the clearness of the lung shadow, which the ordinary normal position of the tube would not do owing to the shadow thrown by the diaphragm (see Diagram B).

Even with the aid of an oblique examination we shall sometimes be at fault in cases in which pleurisy has ended

in a process of adhesions with complete disappearance of the costo-diaphragmatic notch, causing an abnormal aspect of the diaphragm which may present the appearance of a concavity at the upper border, and especially the disappearance or considerable limitation of the movements of the diaphragm. (See Plate V, Fig. 4.)

§ 49. **Abdomen.** — Intra-abdominal sub-diaphragmatic projectiles belong to the class of which it is often most difficult to determine the exact topographical site by X-ray examination; this must be partly ascribed to the uniformity of abdominal shadows which do not easily permit a differentiation between the different organs. It will be advisable in certain cases to facilitate the examination by inflating the large intestine with gas in the manner recommended by one of us long ago, which will often indicate the limits of the various organs in a useful manner. Finally also and especially after this inflation very important information will often be obtained by a lateral view.

In the case of the thorax, but to a much lesser degree, the study of respiratory displacements will be of use. One must not forget the movement of the liver in contact with the diaphragm, nor that of the right kidney moving with the liver. On the other hand, palpation, almost useless for the thorax, will be of great assistance here, and will furnish us with important data. Care should be taken to examine the patient both in an upright position and lying down, making him turn over on his side in the latter position. It will also be very useful to examine him by the Trendelenburg method, but few tables, with the exception of the radio-surgical table, constructed for us by the firm of Gallot (§ 15), lend themselves conveniently to this practice. This method will reveal by the movement of the projectile its site in the omentum, in the lumen of the intestines, the colon, or certain parts of the mesocolon, or, although it rarely occurs, whether it is entirely free in the peritoneal cavity. Palpation will complete these data in a useful manner.

It must not be forgotten as regards intra-abdominal projectiles, that they may penetrate by gradual breaking down of the walls into the cavity of certain hollow organs, and be thus eliminated sometimes through the natural channels

It will be possible, in certain cases (Viallet), especially with regard to the bladder, to suspect the site of the projectile as being inside a hollow organ when by localising alternately from the back and abdomen, results are obtained which disagree as regards the total thickness of the subject, and are notably less. This is explained by the displacement of the projectile from one position to the other.

It should be noted that in order to obtain good results one must not neglect in these deductions the various causes of error and one will always associate together clinical surgery as much as possible with the X-ray examination.

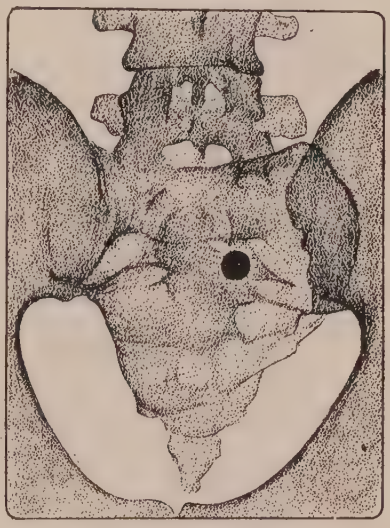


FIG. 187.—Tracing of a radiograph seen from behind. The shrapnel bullet of which the shadow is seen was 9 cm. from the dorsal skin. It was impossible, according to these data, to know with certainty whether it was lying in front of the sacrum, and at what level, or whether, on the contrary, it was included in the bone, a question which presented much interest from the operation point of view. (See Fig. 188.)

§ 50. **Spine and Pelvis.**—*The Vertebral Column.*—It is perhaps with regard to the spine that the necessity arises for two plates at right angles to each other, that is to say one antero-posterior and one lateral negative, and makes itself felt most frequently and urgently, to judge by the number of observations on this region to the effect that operation was abandoned "in order not to cause too great damage." These assertions, which remind us of the now legendary phrase of the communiqués with regard to the voluntary falling-back of troops to a position prepared in advance, are in reality inadmissible in most cases. On going into the matter, it will be found that they refer nearly always to cases in which a lateral negative was not taken. Screen

examination is not sufficient here, as it does not provide enough detail. It is however known that lateral radiography of the spine is difficult, although this seems to us absolutely unjustified, and we consider that it is generally avoided without proper reason. Besides, it is not a question of making show negatives, but only negatives which enlighten us about the exact site of the projectile in relation to the spine. This is always possible for the cervical column as well as for the lumbar column, and even for the sacrum, as is shown by the radiographs which we are constantly taking at Tours, where not a single spine is operated upon without this precaution. (See Figs. 187, 188, 189, and 190.)

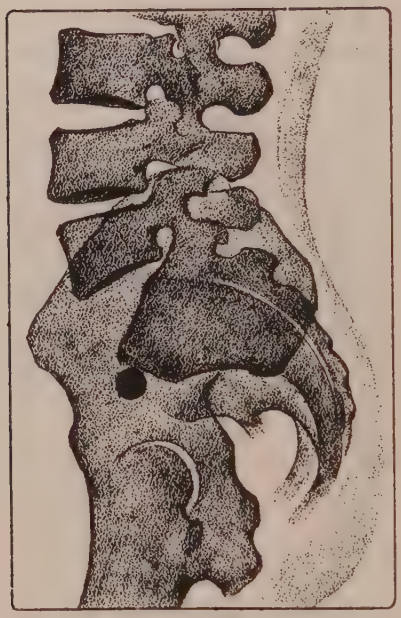


FIG. 188.—The tracing of this radiograph of the same patient as in Fig. 187 shows us the pelvis seen from the left side, and shows the projectile as placed on the promontory. We know now exactly its anatomical position.

From our negatives from the front and side we know exactly where the projectile is situated in relation to the bones, and moreover we know the condition of the bones. Therefore, if we decide to operate, it will be with the full knowledge of the matter, realising the damage we are bound to cause and being quite determined to extract the projectile from the moment in which, having resolved to look for it, we have consequently been able to plan out the exact procedure to adopt in spite of the damage inevitably caused.

It must not be forgotten that projectiles are able to move in the spinal canal, which explains the non-success in the use of the compass in similar cases.

The Pelvis.—Projectiles in the pelvis present some special difficulties from the point of view of the determination of their site. One may be dubious in the case of those which are near the iliac bone, even when we have our negatives and have determined the depth, knowing the projectile is for certain in front or behind the bone, or included in its thickness. In such cases stereoscopic radiographs or radiographs taken according to the Belot method will help to solve the difficulty.

When the projectile is supposed to be near the rectum, the practising of "rectal palpation" under the screen will be useful.

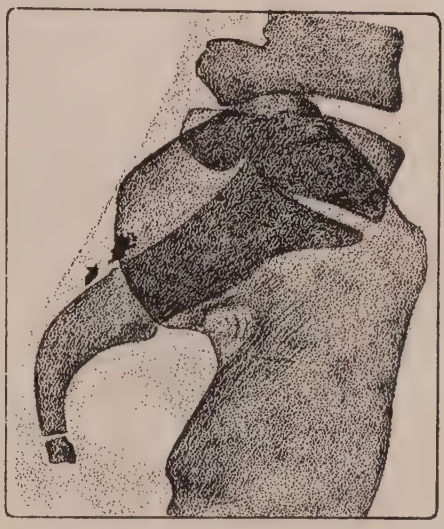


FIG. 189.—The tracing of this radiograph of the pelvis, as seen from the right side, shows us that the splinters which were localised respectively at 44 and at 33 millimeters from the skin of the sacral region are in the soft parts and that their extraction is extremely easy.

§ 51. **Upper Limb.**—*The Shoulder.*—This is one of the regions in which the extraction of projectiles is often difficult on account of the presence of the scapula on the one hand, and of the axilla with its large vessels and nerves on the other. It is therefore one of those parts for which the exact particulars furnished to the surgeon about the exact site will be of greatest help to him, as the judicious choice of the best route of access depends upon this information. The following indications are mainly taken from Viallet.

Let us presume that we have to deal with the examination of a patient who has a shell splinter in the shoulder region. We have placed him on the X-ray table on his face, and we have ascertained that the splinter is neither in the lung nor parietes. It only remains now to consider

its relations to the scapula. In order to find out, we ask our patient to keep relaxed, and we take hold of his arm near the elbow in order to raise and lower it successively. The whole scapula will follow, showing a wide range of movement. We may see the shadow of the projectile moving at the same time seven to eight centimeters. In order to confirm this result further we then tell the patient to put his hand on his head and then to place his arm along the body. The scapula describes thereupon a movement like that of a bell, which the projectile follows more or less accurately.

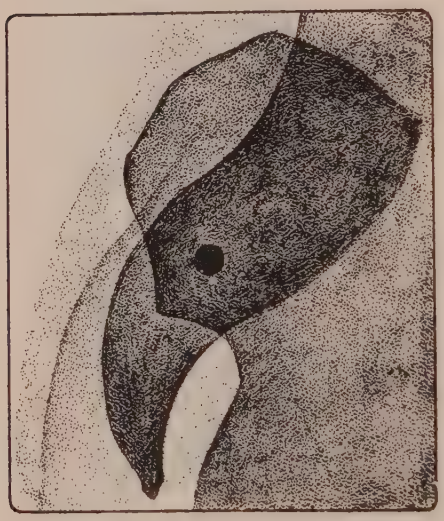


FIG. 190.—This tracing shows a piece of shrapnel embedded in the sacrum.

As the projectile moves with the scapula we know that it can only be in the subspinous fossa, in the thickness of the bone itself, or in the sub-scapular fossa. Palpation and movement of the tissues as well as the knowledge of its depth should furnish us with the desired data for determining its situation, being helped, if necessary, by all the resources of radiography.

Let us now take a projectile which we suppose appears in a position in which it lies over the head of the humerus. The patient will this time be on his back, the arm is in abduction and the fore-arm bent on the arm. In the first place we must make sure, by moving the soft parts in front or at the back, that the projectile is neither in the mass of the pectoral nor latissimus dorsi muscles. It is therefore either in the joint or embedded in the head of the humerus.

In order to be certain, let us make the head of the humerus describe a rotary movement in its glenoid fossa

by moving the fore-arm, keeping it bent at 90° on the arm, the latter being in abduction at 90° on the trunk. If the metal fragment is near the capsule, the movements of the latter will cause it to change in position. If it is in the head of the humerus, the movement of the latter will communicate to it more or less important displacements according to its situation as regards the ray passing through the centre of the sphere to its periphery. If it is exactly in the centre of the sphere, it will remain immobile or almost immobile. If it is on the surface, the movements will have their greatest amplitude.

One can, besides, be guided by the fact that one of the tops of the bicipital grooves generally shows on the screen a long clear shadow which is easily recognisable, the relationship of which to the shadow of the projectile on rotation gives us useful information. So when the projectile is clearly on the posterior side, a change of position is produced between the two shadows during the rotation of the head.

Moreover, those observations made in paragraph 13 with respect to intra-osseous projectiles and their little areas of decalcification should not be forgotten.

It is, besides, only on negatives—and good negatives—that these details will be seen.

It has often been claimed that one special difficulty in the good localisation of shoulder projectiles arises from the impossibility of taking satisfactory images at right angles to each other in that region. This, however, is a complete error. It is perhaps somewhat delicate, but not at all impossible to take a lateral view. Moreover, one can still take a negative through the axilla in the case of patients who are not affected by complete ankylosis of the shoulder.

Arm, Elbow, Fore-arm, and Hand.—There is very little to add as regards these different segments of the lower limb. What we have already said applies also in these cases as regards localisation. The elbow and carpus will be the only two parts which are somewhat delicate and require good negatives which are indispensable for appreciating the state of the joints, the knowledge of which is generally important for operation.

§ 52. **Lower Limb.**—*The Hip and Thigh.*—One must not

forget that the hip is, like the shoulder, an especially difficult region, and for which an exact localisation is of great importance for the surgeon, as this alone gives him the correct information necessary for choosing the proper route of access. He should therefore never undertake an operation for the extraction of a projectile which is somewhat deep in the region of the hip without being absolutely certain about the situation of the metal fragment in relation to the femur, and without knowing whether it is above within or below the neck, for instance. The screen examination may be rather difficult in these cases. One must always try, when executing it, to move the neck of the femur by rotating the foot alternately from side to side.

FIG. 191.—Tracing of a radiograph of the right foot seen from the plantar aspect. A shrapnel bullet is seen at the level of the middle part of the third metatarsal. As it was very movable through palpation of the sole of the foot and was situated 6 cm. from a point on the dorsal surface, it was therefore in the soft parts of the sole at 1·5 cm. away from the latter, the thickness of the foot, measured at this level, being 7·5 cm. Operation by lateral incision is indicated (see Chapter XVI).

The difficulty in taking a lateral negative is greater here than in the region of the shoulder. One may however do this successfully and obtain if not marvellous negatives at least plates which give the required information. Stereoscopic radiography is also of the greatest help.

We may see—and it is as well to recognise the possibility of this—projectiles included in the head of the femur without any lesion or bony change visible in the negatives: these are generally pieces of shrapnel. We must not mistake in radiographic examination the small trochanter for a piece of shrapnel nor the area of osseous condensation of the cotyloid ridge for a piece of shell splinter (see Chapter V).

In the soft parts of the buttock and of the thigh the search for projectiles, especially of small splinters, is also

very laborious on account of the considerable changes of situation which the slightest modification in the attitude of the limb may cause between the position during localisation and the position during operation. Pierre Duval stated (see also Chapter XIII) that a rifle bullet situated in the adductors was displaced seven centimeters, and we have noticed similar displacements ourselves on various occasions.

Palpation under the screen with the aid of a rigid rod will be of great importance here for the determination of the exact site.

Knee, Leg, and Foot.—As floating projectiles are particularly frequent in the knee joint, account should be taken of this fact. The determination of the exact site is always very easy in the region of the knee and leg. For the foot, stereoscopic negatives will often be of service which will be much appreciated by the surgeon, enabling him to see for himself the exact situation of the foreign body.

The above remarks apply, it should be noted, to cases of embedded pins and needles, of which the knee and the foot represent, together with the hand, the most common situations, the extraction of which will only be executed in future, let us hope, with the aid of the fluoroscope.

§ 53. **The Migration of Projectiles.**—After having examined thousands of persons with projectiles in their bodies, many of them several times, and at very long intervals, we are under the impression that migration of projectiles is infinitely rarer than one would believe when judging from the well-known fact of the migration of needles. It is besides sufficient to have extracted projectiles which date back for some time from cicatrised wounds, and to have seen the trouble one has in liberating them from their fibrous capsule and in extracting them from the tissues in which they are embedded, to be sceptical about the possibility of their changing their situation in the body, excepting certain well-established cases.

Brain.—The migration of brain projectiles with the tendency to occupy the most sloping point of the head of the patient when lying down (occipital fossa) is well known. The same tendency to migrate is noticed with respect to the projectiles causing by their presence an abscess of the brain. This explains itself.

Serous Membranes and Joints.—In the splanchnic serous glands as well as in the joints one finds very often free projectiles which are consequently very movable, but one can hardly call these cases of genuine migration. The same is the case with regard to free projectiles seen in the spinal canal, of which we have met a few examples, and with respect to projectiles in the omentum (see Chapter XVI).

In the neighbourhood of all the *hollow viscera* one can confirm the passage of a projectile into the organ We have thus observed the passage of a projectile lodged near it into the œsophagus and its elimination by the natural channels.

Similar occurrences have been noted with regard to all parts of the digestive tract, with or without elimination through the natural channels. One has also observed the passage of one into the bladder, and we had occasion to extract a rifle bullet from the bladder of a man who has never had hæmaturia, and in this case it is probable that its entry into the bladder was a secondary result. (See also the interesting communications by Legueu, *Soc. chir.*, 1916.)

Of less frequency are migrations in the respiratory apparatus. In a case known to us a violent attack of coughing caused a projectile to pass into the other lung in the course of an operation being performed for its extraction. This projectile in the bronchus was, moreover, spontaneously expelled afterwards during coughing.

We also know of the existence of some migrations of projectiles through the course of blood vessels. The best instance is doubtless that of Grandgerand, in which a projectile which was at first lodged in the heart, was extracted from the femoral vein. The relative frequency of intracardiac projectiles will no doubt multiply these kinds of observations. Finally we must mention the possibility of the migrations of projectiles which follow the paths of purulent fistulæ. This is well authenticated and moreover quite logical.

Apart from these various eventualities, even if we strictly admit the possibility of certain migrations of projectiles, we see nevertheless that they must be absolutely exceptional, and we ourselves have never met with a definite example.

CHAPTER XII

INDICATIONS AND CONTRA-INDICATIONS FOR THE EXTRACTION OF PROJECTILES

THE close collaboration of radiology and surgery has caused such progress to be made in the methods of the extraction of projectiles that in a certain number of units the percentage of successes varies between 95 and 100%. This great success under favourable conditions has caused some surgeons to make it a general rule that *all* projectiles should be extracted.

We do not share this point of view, although we have so far been successful in extracting all projectiles which we have searched for at our Central Service at Tours.

Two factors must be considered and balanced in our opinion when it is a question of deciding whether or no such a foreign body should be extracted: *the trouble resulting from the presence of the projectile in the body must be weighed against the inconvenience or dangers resulting from its extraction.*

It is evident that this balance can only be established after the patient has been screened and when the situation and the depth of the projectile in relation to certain points marked on the skin have been accurately determined.

§ 54. **Indications for Operation.**—TROUBLE RESULTING FROM THE PRESENCE OF THE PROJECTILE. This trouble varies considerably with the situation of the projectile. Nevertheless it can be classified under two heads: pain and functional trouble.

Pain.—This varies from simple inconvenience up to the most severe pain. For instance, shell splinters situated in the sacral-lumbar mass, in the muscles of the vertebral grooves, cause inconvenience. These foreign bodies cause much pain on bending forward and prevent the patient from stooping.

On the other hand metal fragments running through a nerve trunk or situated in the substance of a thick never, like the sciatic, give rise to great pain. We have seen a certain number of these cases.

However, it often happens that a patient who has a projectile in a region generally slightly sensitive, for instance the mass of the gluteus maximus muscle, suffers pain of an intensity which is quite out of proportion to what might be expected. It is said that it is absolutely impossible to walk with a small splinter situated in the soleus or in the gastrocnemius muscles.

Is it necessary to admit that the foreign body is in certain cases in direct contact with nerve endings directly irritating them ? This is possible, and this hypothesis would indicate the necessity of removing it.

Can it be believed that this foreign body plays the part of an irritant provoking a reflex contraction which produces considerable inconvenience in walking ? This explanation is no doubt valid in a certain number of cases, and the experience gained since the war shows us that these contractions resist every treatment, until the irritant which gives rise to the spasm has been removed.

It is however right to consider the part which the psychical condition of the wounded man may play in the production of the pain from which he says he suffers.

It is certain that a fairly large number of patients exaggerate the inconvenience and the pain which a retained projectile causes them, but we are convinced that it is mostly a question of unconscious rather than voluntary or reasoned exaggeration.

This unconscious exaggeration may moreover vary very much in its amount. Sometimes it is a question of a patient who has heard the doctors and nurses around him expressing serious apprehensions or a serious prognosis from the point of view of the recuperation of the injured limb. Upon his organism weakened by his wound, on his nervous system shaken by the battle, the suggestion will have great effect, and the patient, who retains a small fragment of metal in the calf, who has been told not to rise because he could not walk, is really unable to walk when asked to do so.

This exaggeration may make him hysterical. We have

heard wounded men complaining of violent pain because they thought they had a projectile in a part of the body which they indicated, but which only existed in their imagination.

Finally, in the case of certain very much depressed patients we have noticed a serious neurasthenic condition accompanying the persistence of a projectile in the tissues. They were troubled about the future, asking themselves what troubles this foreign body may cause, what accidents it may lead to some day, and this fixed idea was continually present in their minds. They only thought of their projectile, continually feeling the region where they thought it was situated, and analysing the pain which they thought it caused them.

In our opinion, account should be taken of this unconscious exaggeration of the pain caused by a projectile in the body. Not only do we not refuse to extract a projectile seated in a muscular mass, for instance, in the case of one of these exaggerators, but we think that this operation, if it is simple and without undue risks, is the most rapid and the best means to dispel all the troubles complained of by the patient as well as all the pain which he says he feels.

We therefore consider it advisable to take account not only of the wishes of the man, but also of the degree of pain which he says he feels, even if we have reason to think that the pain is involuntarily exaggerated by the wounded.

If we think this exaggeration is voluntary, we shall follow the same course and, except in the cases of the contra-indications which we shall mention hereafter, we shall advise the extraction. Moreover, this is one of the best procedures which we have for recognising in this exaggeration the part of a conscious will, as we shall then meet with a refusal to operate. However, we say again that we think these cases are very rare.

Functional troubles.—They evidently vary with the regions and the organs in which the projectile is lying. Giddiness, epileptiform crises, hæmoptysis, diminution of air entry to lung, hæmaturia, paraplegia and syndrome of the cauda equina are the most frequently observed. We shall mention these again later, region after region. We must balance the indication for operation against the danger and the damage that may be caused by the operation.

§ 55. **Conditions Favourable for Extraction.**—Amongst

the motives to be considered in deciding upon an extraction, certain conditions of the situation and size of the projectile must also be mentioned.

One will hesitate less in deciding on the extraction of a large projectile, situated at a small distance from the skin, sometimes perceptible to careful palpation, situated in a region which is not traversed by important vessels or nerves, than if the contrary were the case.

FIG. 192.—Radiograph of the left fore-arm seen from its ulnar side. A trail of metal dust will be noticed in the soft parts (grenade).

§ 56. **Contra-Indications to Extraction: Danger and Operative Damage.**—Every surgical operation, no matter how small, always involves some danger. We shall not deal further here with this point of general surgery.

Danger.—The extraction of projectiles involves however special risks according to the region in which they are retained, and we shall consider them with the regions. The consideration of this risk should be weighed when it is a question of deciding for or against operation. These operative risks are limited almost exclusively to hæmorrhage coming from vessels of such importance that it will be very difficult to control it. We shall deal with this presently.

Besides the danger of which every surgeon thinks who knows anatomy, the operative damage to adjacent tissues must be taken into consideration beforehand, and we are under the impression that it is not sufficiently considered in a great number of cases.

Operative damage.—A projectile is situated in the pterygo-maxillary fossa, where it causes extreme inconvenience. In order to extract it the zygoma must be cut, the masseter must be detached, the coronal must be cut, and the temporal raised. Will not the functional inconvenience resulting from these various disturbances be more important than that which is involved through the presence of the foreign body?

The effect of the operative damage, of the incisions in muscles, of the cutaneous scar which will result from the operation, must therefore be carefully estimated before the decision is taken to extract a projectile.

Unfavourable conditions.—The smallness of the foreign body is a relative contra-indication. We have been compelled to look for a metal fragment smaller than a grain of corn because it was adjacent to the ulnar nerve in its epitrochlear groove. We should not look for the same fragment in the gluteus maximus, because the operative damage done would be out of proportion with the existing injury.

FIG. 193.—Radiograph of the right hand seen from its palmar side. At the level of the three first inter-osseous spaces especially very numerous metal splinters are seen, the largest of which is hardly bigger than a grain of corn, with innumerable fragments of metal dust, the excision of which is obviously impossible.

Its depth also is a relative contra-indication, for the same reason. Finally, the same is the case when a large number of small metallic foreign bodies are present.

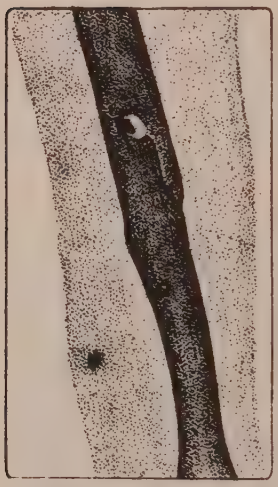


FIG. 194. — Radiograph of the right arm seen from its posterior aspect. A shell splinter is visible and is seen in the shadow of the humerus at the level of a cavity (clear zone), without doubt hollowed by the projectile at the moment of its penetration. The diaphysis of the bone was split from that point, and one can still see the presence of this fissured fracture united with slight deformity. The persistence of suppuration, the X-ray aspect of the osseous cavity, hardly half filled up by calcified tissue one year after the wound, allow the supposition that the process of osteomyelitis, although *clinically* stopped, is yet still latent and that the extraction will determine its recrudescence, which in fact frequently happens.

Besides, it is often the case when these innumerable small fragments are searched for that no real metallic masses are found, but a kind of incrustation, a tattooing of the tissues by metal dust. These metal splashes occupy especially the cellular tissue and the aponeuroses (Fig. 193), incrusting the tendons. It is impossible to remove them without excising the tissue which contains them. In this case also the damage is out of proportion to the foreign body to be extracted.

We must bear in mind also that certain extractions will almost certainly result in complications. We wish to mention projectiles which remained included in the centre of old foci of osteomyelitis complicating fractures. We have come across this eventuality especially in the case of men wounded in the first months of the war, when only a few rare units possessed X-ray installations. A fracture caused by a bullet united more or less well, but a fistula persisted. This is attributed to the osteomyelitis, all the more since through its orifice splinters were eliminated. The fistula heals up and the patient is considered cured. We have seen such wounded patients coming back to the hospital on account of persistent pains at the site of the old lesion. An X-ray examination revealed the presence of a metal fragment in the osteomyelitic cavity (Fig. 194).

In these cases it is rare that the extraction is not accompanied by a fresh outbreak of osteomyelitis at

the level of the central part, and that a fistula does not persist afterwards for a variable time.

These are briefly the elements of indication and contra-indication for the extraction of projectiles.

§ 57. **Anatomical Situation of the Projectiles.**—We have mentioned above the dangers of certain extractions due to the vicinity of important organs. This implies an exact anatomical knowledge of the situation of the projectile. There are cases when this is easy to presume; there are others when it is particularly doubtful, because the figures of depth supplied by radiology are of no absolute value and vary according to the subjects. (See Chapter XI.)

A wounded man has a shrapnel bullet eight or nine centimeters deep from a mark situated in the dorsal region, three centimeters from the median line. He suffers referred pains in one side of the chest.

If it is a man with strong muscles and very tall, the projectile will probably have its seat near the nerve root orifice; it can, by its mere presence, determine the painful phenomena from which the patient suffers. If it is a small and weak person, the projectile may be seated on the side of the vertebral body, at the level of the great vessels. The pains in that case are no more attributable to the projectile, but they are due to the lesions it has left during its passage, and they will probably persist after the extraction. The extraction will, besides, be much more dangerous on account of the presence of the pleura and the great vessels.

In such cases we never hesitate to call for a supplementary investigation, consisting in the taking of a fresh radiogram at another angle, especially the side view, and in a fresh examination under the screen if there is a doubt as to the anatomical localisation of the projectile (we have seen, in § 48 above, what is important with regard to projectiles near the spine from the point of view of their localisation by X-rays). The side view of the dorsal spine allows us to appreciate the relations of the projectile to the vertebral body or the transverse process.

We have also frequently asked for a supplementary profile view at the level of the sacrum which gives us the most useful indications in order to establish the anatomical position of the projectile.

From this information we obtain a most important operative indication, namely, the route of access.

§ 58. **Surgical Route of Access.**—The choice of a good way of access is a problem which has not to be faced in the case of recently injured patients, the wound of which is still widely open. In these cases the projectile will be removed most advantageously through that wound in a very large number of cases.

The case is quite different with wounds of old standing which are entirely healed.

In such cases the surgeon must select a route which is at the same time the shortest available, and which enables him to avoid the important organs which may be encountered. A bullet for instance is intracerebral and exactly in the median line, four centimeters deep. It will be advisable to approach it outside that line in order to avoid the superior longitudinal sinus, and the passage made will have to be somewhat long. A close collaboration between the surgeon and the radiologist in these cases is necessary to ensure consistently successful results. Whenever the X-ray examination could not take place in the presence of the surgeon, the latter should not hesitate to ask for a confirmatory investigation. In the particular case under review, if the localising mark on the patient is nearer the middle line than is desired by the surgeon, the latter should ask for a fresh indication of depth from a favourable point of access exactly indicated by him

It is only after having reduced to a minimum the factor of danger, by judiciously choosing the way of access, *even modifying it several times*, that the surgeon will be in a position to decide whether the extraction of a projectile should be advised. We are under the impression that at the rear, where the surgeon is never, as at the front, worried and compelled to somewhat hasty decisions, he does not perhaps take all possible precautions before deciding to intervene or not.

The formula which guides us is the following :

A projectile should be extracted when the dangers and destruction of tissue necessitated in its extraction are less than the pain involved.

§ 59. **Conditions Bad for Extraction.**—This formula however was made for the Central Services, where we do not

consider any chances of failure, as our material installation and the method we employ give us the certainty of carrying through our extraction if our localisations are correct.

All units during this war and all practitioners after the war cannot always reckon with such perfect material conditions.

The X-ray installation may be insufficient to enable us to carry out an extraction with the aid of the intermittent control of the screen, or the available local supply may only lend itself with difficulty to the execution of the work. In such cases as we have already seen the X-ray cars attached to the bases may nearly always be substituted for the local installation. The same will be the case when the outfit required for localisation, which can easily be improvised however at small cost, is not provided.

What will often be wanting more than the outfit, especially during the period of the war, is the competent radiologist who is capable of utilising it (see Introduction), to supply the surgeon with exact data, and to guide him with precision and safety. This is therefore purely a question of personnel.

Although it is indispensable to possess extensive medico-surgical knowledge in order to do one's very best as a radiologist, the title of doctor is not sufficient to make one a specialist.

We have met radiologists, medical men—at least as far as the possession of the diploma goes—who took the end of the coracoid for a shrapnel bullet, organic calcifications for projectiles, directing the surgeon at the beginning of his operation, then changing their minds about the shadow which was at first taken for that of a metallic foreign body and finally giving up the search.

On the other hand we have seen, it is only right to say it, a pupil of the Beaux-Arts School who before the war had no knowledge whatever of radiology, but who possessed sound notions of anatomy, become in a few weeks a collaborator sufficiently competent to enable the surgeon of the place where he was acting as assistant to obtain a series of 100% of successful results.

The operator—just the same as the radiologist—may be

incompetent. We have seen one passing under the foreign body, displacing his incision after the localising mark was applied, deviating every minute from the vertical line he should have followed, and which the radiologist had just indicated to him.

Others are constantly searching with the fingers for an illusory tactile sensation ; one does not feel when touching a small foreign body encysted in muscle, or one takes for the foreign body a fibrous cicatrised module left by the passage of the projectile. These are solely and essentially questions of individual technical skill with which we shall not deal any further. It is quite evident that a bad surgeon and a bad radiologist together will never do any good, and if one of the two collaborators is inefficient, the work executed can only be mediocre.

In order to obtain the best results in the extraction of projectiles good surgeons and good radiologists who have good outfits and who are efficient are necessary.

When all these conditions are fulfilled, the experience of this somewhat special surgery affords the operators a much greater rapidity and certainty. We have had personal proof of this.

Moreover, without going as far as to ask for a special service at the base for the extractions of projectiles, we nevertheless think that *one would obtain better results from the point of view of rapidity and efficiency by using for preference real centres for extraction, where there is an equally competent radiologist and surgeon.* This suggestion has besides been made on the rostrum of the Academy of Medicine by Prof. Laurent.

The services of consulting surgeons and those of some local surgeons are all intended to play that part.

If the resources in outfit and staff are insufficient for endowing every one of them with a connected radiological service, the X-ray car of the region can be attached periodically to the surgical service which undertakes the extractions. This organisation is in operation in the ninth region, where we arranged it a long time ago.

However, the above only applies to the base. The conditions are different at the front. While there are at present many special ambulances supplied with excellent X-ray installations, there are also other ambulances to which the

wounded can come, in case of emergency, with projectiles at the bottom of open wounds. In these cases extraction is often easy, the projectile felt by means of a probe at the bottom of the gaping wound being easily removed with a curette.

There are more complex cases in which the intervention of radiology plays a part, but where the circumstances, the outfit, and the pressure of time necessitate—or rather have necessitated—methods which are not precise. The enormous progress made in the organisation of the health service since the beginning of the war justifies the hope that such chance procedures will be less and less used.

CHAPTER XIII

PROCESSES OF EXTRACTION

They can be conveniently grouped, in a general manner, under three headings : The chance processes, the precision processes, and the processes of certainty. We are going to study these three groups in succession, considering only the surgical side of the question, as the radiological aspect has been dealt with in detail in the previous chapters to which we refer the reader.

§ 60. **Chance Processes.**—*Two images in perpendicular planes.*—Two images obtained in two perpendicular planes give, as we have stated above, very useful information from the topographical point of view. A projectile which is from front view on the external edge of the patella, for instance, and from profile appears to be in contact with its posterior surface, is sufficiently well located that one can be almost sure to find it *if it is of sufficient size.* But this process can only be of value in certain regions of the limbs where it is easy to make a localisation from bony points. Generally it is absolutely insufficient. Exactly the same will apply in the processes based on radioscopic examinations in two directions by marking the points of emergence of the rays on the skin and materialising them in any way whatever in order to obtain the situation of the projectile which is at their point of intersection. We refer to what we said in Chapter VIII about these various processes, remarking once more that they are only applicable to the limbs. We shall only mention here specially the ingenious variation called the lead bracelet, which one of us has employed with Haret at the beginning of the war, when the first X-ray car came to the military hospital at Verdun where no permanent installation existed at that time.

On that day a large number of projectiles were thus removed by the use of this method alone. But the operator retains the mortifying recollection that he was not able to find a whole rifle bullet placed vertically and parallel to the humerus. This process may therefore be of great service, but no precision can be claimed for it.

Anatomical localisation.—Further we still classify amongst the chance processes the extraction practised after an anatomical localisation.

The latter when it is well carried out and accompanied by an accurate knowledge of the depth of the projectile is certainly one of the most satisfactory and least fallacious processes, especially in the case of projectiles of a size sufficiently great that they can be felt, and M. Robineau has been able, on the anatomical localisations with depth gauge made by Viallet, to extract 52 projectiles out of a series of 54, viz. about 96% of successful results.

Nevertheless, the fact that one has not at one's disposal any means of assistance when the projectile is not found at its supposed site, and the facility with which even fairly large metal splinters may escape our touch, especially in muscular masses, indicates, we think, quite well that we have here only a part of the information needed for successful extraction and that it requires to be completed by a method of guidance and control in order to become a process of precision.

Needle process.—We also count amongst the chance processes, in spite of its appearance of certainty, the process which consists in sinking a needle through the soft parts during the screen examination until its point comes into contact with the projectile. The patient is then taken to the operating theatre. The operator follows the needle and comes down on the foreign body.

This method has been recommended by a large number of German and Austrian authors, and it is difficult to say who was the real originator of it. In France, it has often been used with success by Charlier, Vergley, etc., whilst some people have adapted to it the method of a needle bent at right angles suggested by Wullyamoz (see later).

Although it may be thought that these needle pricks are harmless, we are, however, of the opinion that puncturing

at random is not without danger because the needle may meet a nerve or a large vessel. Then, in the darkness of the X-ray room, the deeper the foreign body is, the more chance there may be of such an accident occurring.

However, this is not the principal objection we have to this process. It is not very difficult to insert a needle by following the normal ray, but it is then not easy to see on the screen, since it only shows as a point. On the other hand, if the needle is inserted obliquely in relation to the normal ray the method is far too laborious. We may put it in above or below, and it may be necessary to puncture several times before coming down on the projectile. In fact, there is no guide whatever for knowing the level at which to aim unless we are dealing with a limb which can conveniently be examined in two different planes during this small operation. These repeated punctures are not without inconvenience. The method which consists in inserting several needles multiplies these inconveniences, and the more or less ingenious devices proposed for facilitating and rendering the correct aim more certain demonstrate that the problem is only simple for superficial bodies which can easily be removed in any way.

Moreover, the needle must be sterile. It can therefore not be handled by a hand in a protective glove such as that of the radiologist. The surgeon who locates it by searching with an unprotected hand is exposed to the rays to a very considerable degree, which we consider is sufficient to condemn this procedure. Finally, is there a surgeon who would willingly use it, in certain dangerous regions, without any exact data as to depth ?

There is, besides, the possibility of the needle moving during the inevitable movements between the X-ray examination and the extraction. This is a fatal drawback, as there are no further means for re-establishing the lost route.

We are therefore right in classifying this method under the head of chance processes. It may often be useful, but it cannot be raised to the position of a general method and used systematically. We think it can only be recommended for certain units at the front, where one must try to work quickly and well—that is to say, remove the largest possible number of projectiles with the minimum of damage, and

where one will thus save much time for intramuscular splinters in particular. (See the article by MM. Averous and Gouin in the *Journal de Radiologie*, T. II, No. 4).

§ 61. **Precision Processes.***—We describe as precision processes those which are based on the use of *mechanical guiding apparatuses*, commonly described by the generic term of *compass*.

These instruments, the compasses by Contremoulins, Hirtz, Saissi, Marion-Danion, have already been studied (Chapters VIII and IX) from the point of view of the theories of their working, their details of construction, and their regulation. We shall therefore only speak here of the *surgical* occasions for their use.

Theoretically, the preceding calculations being supposed as correct, and the regulation exact, if the projectile were immobile and the compass applied on an unalterable solid part, the information furnished by the indicating needle would involve a mathematical certainty.

In practice, errors of calculation and of regulation are *almost impossible*, unless the radiologist is unskilful, because certain signs, such as the absence of horizontality of the three fixed arms of the Hirtz compass, for instance, would notify the error.

Movement of the projectile inside the tissues of the body is very rare, still it sometimes happens. In that case the compasses would lead to a fatal error. However, the fact that the human body is susceptible to change of shape is the great cause of error in the use of this apparatus. The various manifestations of this susceptibility to change of shape should be studied in detail.

We shall deal successively with the extraction of projectiles with the aid of the compass, then with the inconveniences, the causes of failure, and finally with the total results derived from this apparatus.

The extraction of a projectile with the aid of a compass.—We shall describe here the extraction with the aid of the Hirtz compass, perhaps the most valuable and the most

* One should not fail to refer to the excellent article by Pierre Duval: "The method of extracting projectiles under the guidance of the Hirtz compass," conference held at the Ocean ambulance, at La Panne (Belgium), published in the *Revue de Chirurgie*, January 1st, 1916.

frequently employed at present, without doubt, of all similar apparatuses.

The compass has been regulated as stated above. As every surgical unit can probably only possess one compass, this apparatus should be sterilised very often by boiling. The Poupinel sterilisation can only be effected for the first projectile of the series to be extracted. It would take too long to repeat a hot-air bath sterilisation between each operation, or even between the extraction of the two projectiles in the same patient.

The radiologist who will make the "trials" washes his hands and puts on gloves, if necessary, as the surgeon's assistant.

Pierre Duval * describes the operation as follows:

"When the patient has been anæsthetised and the compass has been put in place and the penetration needle brought in contact with the skin, it gives the point of incision, the depth of the projectile, and the direction. The compass is removed. A free incision at the point marked is made, and then without forceps on the skin, without retractors, without any disturbance of the anatomical structures, incision of the aponeurosis, division or separation of the muscular fibres in the direction indicated to a depth about equal to but never greater than that of the projectile.

"At this moment, still without retractors or forceps which pull the planes apart, because, if a vessel had to be clipped, it was immediately tied and the forceps removed, the left index finger is put into the wound. Above the left hand the compass is put in place and firmly held by the radiologist. With the right hand the operator himself takes the indicating needle and presses it down in the route prepared by the left index. If the prepared route is not deep enough or is not in the right direction, the compass is removed, the route put right again or deepened by the grooved probe, then the compass is put back in its place.

"When the needle is at the end of its prescribed di tance, the left index, which has not left the wound, feels the projectile at its point.

"If the extraction cannot be done without seeing it, but only in this case, retractors are inserted, the finger always keeping contact with the projectile.

* Pierre Duval, *loc. cit.*

"The principal factor is not to derange any anatomical plane, not to displace any organ when one has reached the soft tissues."

This is the ideal operation. It is, in short, a research *with the aid of the intermittent control of the compass.*

But the use of this instrument is attended with some difficulties and there are causes of failure.

Difficulties and Causes of Failure of the Compasses.—The three points marked on the skin for the legs of the compass should constitute a triangle which should be as large as possible. As they must not be covered in the field of operation, it makes it necessary to leave uncovered a large area of skin during the operation, which is sometimes an inconvenience. But most of the trouble and lack of success result from the fact that the soft parts of the patient are liable to change of shape.

Attitude.—The patient should lie either on his back or on his belly. It is practically almost impossible to perform an operation with the compasses on a patient lying on his side, as we often have to do in our method, for thoracic projectiles.

In fact, the attitude at the moment of operation with the aid of a compass should *strictly* be the one assumed by the patient during the preceding X-ray examination. The lateral decubitus is essentially unstable and cannot be reproduced with mathematical accuracy.

Even in the dorsal or ventral decubitus it is not always easy to re-establish the identical attitude, which is, nevertheless, indispensable to obtain success. "We have sometimes fixed this position by photography," says Pierre Duval. "A simpler means is to take a simple but strictly exact sketch of the position of the arms, the legs, the head." This "strictly exact" sketch is not always so simple to take.

Muscular relaxation.—"It is indispensable," proceeds Pierre Duval, "to take the radiograph with the greatest possible muscular relaxation, not to put the limbs in a position which necessitates the contraction of a muscular group, because if this contraction were to disappear during the anæsthesia, the situation of the projectile would be considerably altered."

Duval quotes the example of a bullet seated in the

adductors of the thigh which changed its position as much as eight centimeters according as the muscles were contracted or relaxed, and which was missed twice.

"This necessity," he says, "to operate only in complete muscular relaxation makes the extraction of intramuscular projectiles under *Hirtz's local anæsthesia impossible*. The inevitable muscular contractions displace the foreign body and cause it to escape under the finger."

Instruction not to separate the lips of the wound.—It is understood that in order to carry out the Hirtz method in the course of an extraction the lips of the wound must not be separated at the moment of the passage of the indicating needle. However, as soon as the depth attains six to seven centimeters, it is impossible to introduce the needle further without making a place for it at least by one retractor. Moreover, if the needle is not pointed accurately into the line of incision, it acts itself as a retractor on one of the lips of the wound.

The compass now only rests on two localising marks, the two marks situated on the side of the incision which is supposed immobile; the third mark, being displaced, no longer corresponds to the third leg of the apparatus. It is necessary therefore, for the third ordinate, to be satisfied with the horizontality of the three fixed arms of the compass. However, the instrument, being in equilibrium on two legs, has completely lost its precision, since that horizontality is guessed at,* and the two localising points utilised may have been displaced by the forced separation of one of the lips of the incision.

Elasticity of the tissues, muscular tonicity.—There are tissues which when incised are spontaneously displaced. We mention certain aponeuroses, particularly that of the sheath of the lumbo-sacral mass.

In the muscular tissues it is not always possible to separate the fibres parallel to their direction without rupturing any of them. These fibres immediately resume their position on account of their tonicity, and they can, in moving, displace the projectile which is being looked for.

* For further details see the paragraph devoted to the extraction of skull projectiles in particular. It may be useful to add to the compass two small circular spirit levels.

It would therefore seem that the susceptibility to change of shape of the soft parts is the important cause of the failures of the compasses, which possess very great advantages and give the maximum of guarantee of reliability when they are applied to a part of the body which is not liable to change of shape, such as the skull, in which region the localising marks cannot be displaced. Nevertheless—this fact should be well noted—it is for these cranial projectiles that M. Hirtz * himself no longer relies entirely on the compass, but uses an "auxiliary" apparatus for extraction under the screen. We think it would have been preferable to use the intermittent control of the screen pure and simple. But in this respect we are of his opinion. One of us has once missed with the compass an intracerebral bullet with M. Contremoulins, and never since the war have we had a failure with the aid of the intermittent control of the screen.

Failures are irremediable.—When the needle of the compass arrives at the end of its set distance, if the projectile is not in contact with its extremity, the surgeon has no other resource than to suspend his operation and to postpone it to a future date. Whatever may be the cause of failure to find the projectile, whether this was due to a mistake in the calculation, in the regulation, in the horizontality, the elasticity of the skin, the tissues, tonicity, voluntary or reflex muscular contraction under the local anæsthesia or under a bad anæsthesia in general, it matters very little. *If the projectile is not found at the end of the needle, the operation has not succeeded.*

A skilful surgeon still might sometimes be able to find the projectile when it is in a region of little importance from the point of view of the neighbouring organs, and if the projectile is sufficiently large. However, the search is blindfold, without knowing in which direction to feel. The guiding line has been lost and very often reason counsels us not to continue under such conditions.

This is the enormous disadvantage of the compass that one is not able to reset it. On the other hand, the intermittent control enables one to find the direction of the needle again, whenever it is lost.

Mobile projectiles.—It is evident that when a projectile

* Hirtz, *Presse médicale*, 1916.

is mobile in the tissues, it is useless to attempt to search for it with the aid of the compass.

Much more often than one would admit it is very probable that this so-called mobility is frequently only the excuse given for the non-success of an attempted extraction.

That mobility can only be relative. If the projectile is fixed in a mobile organ such as the diaphragm, the displacement is generally not so great that the compass should prove a failure, because the operator is conscious of this physiological mobility if a preceding X-ray examination has taken place (which, as we have seen, should always be the case).

Intrapulmonary projectiles also move with respiration. If the lung is adherent the compass needle still leads to the projectile with fair precision sufficient for practical purposes. However, if the projectile is free in the lung the aid of the compass can no longer be relied upon unless the pleura is open and the pneumothorax produced has allowed the lung to retract.

In order to avoid this difficulty Pierre Duval advises a little artifice which is utilised on arriving at the parietal pleura before opening the pleural cavity.

At the point of the compass needle a curved needle is inserted through the parietal pleura into the lung tissue with a strong suspension thread, then, the lung being thus fastened to the exact point marked by the compass needle the pleura is widely opened, and the total pneumothorax produced slowly, progressively, and without danger. By traction on the suspensory thread a cone of lung tissue is made, the height of which is slightly more than the intrapulmonary depth of the projectile given by the compass. The projectile can then be felt with great ease.

However, if the thread tears the friable pulmonary tissue, the surgeon finds himself absolutely deprived of the aid of the compass and has no other guide than palpation. From the moment when the lung comes into contact with the external air through the gap in the chest wall the compasses become useless. If, in an effort of reflex coughing, the lung escapes the fingers which are holding it and falls back into the pleural cavity there will be no indication as to which part of the lung should be caught and brought out of the wound. We have often seen these cases in which

the intermittent control method would soon show us the position of the projectile.

Finally, we have observed a curious case of great mobility of a bullet in the abdominal cavity. It was encysted the extremity of one of the appendices (fimbria epiploicæ) of ten to twelve centimeters long and moved with it, from time to time, from the left to the right iliac fossa. It is evident that a compass would not have assisted in finding it.

The use of compasses therefore involves a certain number of causes of failure. It is quite certain that these failures will become rarer, the better the surgeon and the radiologist know their work.

The statistics of the compass by Hirtz published by M. H. Barnsby and by MM. Desplas and Chevallier show that they have been able in 138 and 110 cases respectively to extract the localised projectiles without a single failure. In the first and the most important of these series MM. Barnsby and Hirtz were in collaboration, and in both series visceral projectiles were rare. M. Barnsby says, however, in spite of his excellent series of cases, "that he remains a warm partisan of the ingenious and valuable method of extraction by means of the intermittent control of the screen"; later he says that he considers it as "indispensable for the intracerebral projectiles," and that M. Hirtz himself has adopted it for such cases himself, as is shown by his recent article in the *Presse médicale*.

However, the impression obtained is somewhat different when one listens to those who have used the compasses during the war without any previous special experience of its use, and who have only short unpublished statistics on which to form their opinion.

The average results of the Hirtz compass in the hand of the local surgeons will not according to our information exceed 90% of successful extractions, which is in itself satisfactory.

Abandonment of an attempted extraction on anatomical grounds undoubtedly occurs, but it is the result of a badly made localisation. It is common to all methods of extraction. The reason is that the situation of the projectile has not been sufficiently well ascertained, most often because the preceding X-ray localisation, on which the surgeon must

plan out his operation and choose the way of access, was insufficiently accurately made.

Particularities connected with the Use of Certain Compasses.—*Hirtz Compass.*—This is the one we have taken as a type in the preceding explanation. We need therefore not say anything further about it.

Contremoulins Compass.—Although it was perhaps the first amongst the instruments of precision, this apparatus has never been employed except by the inventor himself. Its complexity, its cumbrousness and its price have excluded it from ordinary practice.

Saissi Compass.—What has been said about the Hirtz compass applies to this one at least as regards precision and especially as regards rapidity. This is a very practical instrument and can be recommended for the limbs and the lung. It should be sterilised by boiling, as there is a risk in flaming that the solder will melt.

Marion-Danion Compass.—It has only two localising points on the skin. It should be placed as far as possible in a horizontal position, but this is not so important as in the case of the Hirtz compass. As to the results, M. Marion had 16 failures in 362 projectiles, that is more than 4% of failure. M. Marion says: "I failed in sixteen cases, mostly referring to small shell splinters situated in the muscular masses, or projectiles located in regions anatomically inaccessible." As to the "anatomically inaccessible" projectiles, a preceding screen examination by demonstrating their relative positions would have saved him from having to give up his search for them.

The compasses by Aubourg, Debierne, Grandgerard, Jallot, Morin, etc., do not require any special remarks, and it may be taken that there is very little difference in the surgical use of these various instruments.

All these apparatuses, whilst giving a mathematical precision when correctly applied to solid parts not susceptible to change of shape, lose however greater or less part of that precision on account of the variations of attitude which exist between the patient who is conscious during the X-ray examination and unconscious during the operation, and especially on account of the changes of position of the soft parts which take place in the course of the operation. A skilful surgeon can reduce these displacements, but he

cannot entirely prevent them. Applied to the patient the compasses lose the character of absolute precision which they have in the laboratory. Nevertheless they are very ingenious instruments of admirable ingenuity which have rendered and will still render priceless services especially the Hirtz compass when aided by the screen.

§ 62. **Processes of Certainty.**—All these processes are based on the same principle, viz. : the patient lies on the X-ray couch, the tube under the couch, this enabling the operator to *see* what he is doing or what he should do.

The application of these processes presumes the use of an apparatus producing high-tension current to energise the tube, an X-ray couch under which the tube provided with its diaphragm moves, and a fluorescent screen on which one can follow the position of the foreign body in the course of the operation. But there are two quite different methods for utilising the screen for the extraction of projectiles.

In the first method the operator himself is the observer and picks up the projectile when he sees its shadow and in doing so is exposed to a certain quantity of harmful rays, besides being obliged to work in special lighting conditions which are generally defective. This is *the extraction under the screen.*

In the second method, as the operation proceeds the radiologist demonstrates when necessary the point vertically below which the surgeon will find the projectile. In this case however the surgeon stands back whilst the rays are passing and only returns afterwards. This is *the extraction with the aid of the intermittent control.*

Historical Review.—The idea of utilising the direct control of the screen for the extraction of foreign bodies, opaque X-rays, is certainly as old as the discovery of the rays themselves. It must have occurred simultaneously to many observers and it is difficult especially at present when there is no facility for bibliographical research, to say who was really originator of this method. The following observations have therefore no claim to completeness, but only review the principal stages in this evolution of this radio-surgical technique.

Grashey was one of the first to think of a device enabling one to operate by following the operation with one eye

whilst the other one could examine the fluorescent screen and verify on it the respective position of the foreign body and of the instruments. Fig. 195 gives the outline of the equipment employed and which has been several times taken up again and perfected by the originator and by several other people.

It is however quite evident that the process was only exceptionally applicable in that form. We have said (§ 5) and we have repeated it several times that in order to see well on the fluorescent screen a good receptivity is absolutely indispensable, but this is impossible to realise if one of the two eyes is exposed to the light. Besides the sensation of very great fatigue which results for the observer from the unequal work imposed upon the two eyes, he is restricted in the use of this process to the extraction of foreign bodies situated in very thin and very transparent parts, uch as the hand and the foot.

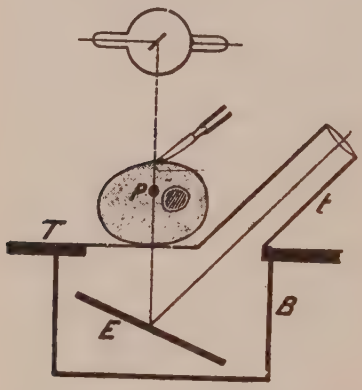


FIG. 195.—The Grashey apparatus. The tube is placed above the site of operation. The part of the body which contains the projectile *P* rests on a portion of the table *T* transparent to the rays, and under which is placed, in a box *B*, being a dark chamber, a fluorescent screen *E*. The surgeon can follow with one eye through the tube *t* the projection on the screen *E* of the shadows of the extremity of the bistoury and of the projectile.

It was this frequent and well-known difficulty in the search for needles in the limbs, especially in the hand, in spite of numerous and excellent radiographs, which caused the method to be evolved, and it was to their extraction that those who practised this combination of radiologist and surgeon had to limit themselves almost exclusively. The evident advantages which ability to see the foreign body in the course of the operation presented to thinking people caused them to look for a method making it available for opaque foreign bodies of he thick regions, that is to

say, in conditions which demanded good radioscopical receptivity. Operations were then undertaken in the darkness of the X-ray room, the tube being placed under the table. The operation took place in feeble light with a coloured or obscured source of illumination. Thus the receptivity was perfect and permitted a sufficiently satisfactory view on the screen, which was placed above the site of operation when its assistance was required. It must be pointed out that in this darkness the possibility of asepsis was often doubtful and that difficult operations in deep or dangerous regions were contraindicated. We need only mention the difficulties and dangers of the anæsthesia. Under these conditions the radio-surgical combination was perhaps still less satisfactory than in the preceding case. Its application is almost exclusively limited to a few cases, surgically simple, most often operated upon the radiologist. Besides, the insufficiency of material at the present moment will not allow the regular use of this method. With the progress of this technique a series of French, American, and German publications have appeared on this subject between 1904 and 1910.

The projectiles searched for with the screen were most often not accurately localised beforehand. At most the two radiographs at right angles or one localising screen examination gave an approximate idea of its supposed site. Under such conditions the search, even under the screen, was sometimes singularly difficult and long, and often unsuccessful. Wullyamoz originated a process which theoretically at least gave certain and rapid access to the projectile.

He uses* to effect the extractions (in any kind of operating room and in daylight, of course employing an X-ray couch and a fluoroscope) instruments, especially his forceps bent at a right angle. The forceps are shown in Fig. 196. The width of the point is only two millimeters, so that it can penetrate easily into the tissues like a needle. The two blades can be slightly separated from the point upwards, so that their image appears on the screen of the fluoroscope and enable the operator to know where the

* Wullyamoz (of Lausanne), *Extraction of Foreign Bodies by means of Right Angular Forceps*, Paris, Maloine, 1911, 8° pamphlet 54 pp., 34 illustrations.

forceps are and in what direction. There are several types in which the length of the bent part is more or less long, according to the depth at which one has to operate. The five illustrations on p. 299 show clearly how the operator who is about to search for a foreign body in the tissues should place the extremity of the forceps in order to reach it. Briefly he guides the bent part of the forceps in the axis of the normal ray which passes through the projectile and causes it to follow exactly that ray until contact is established with the projectile.

FIG. 196.—The right-angled forceps ot Wullyamoz.

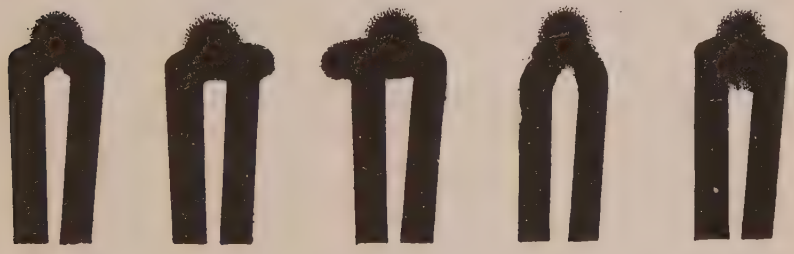
A series of instruments based on the same principle : rectangular separators, hollow needles for local anæsthesia, rectangular bistouries, complete the surgical outfit. All these instruments are difficult to use, and only the bent forceps with short arms should be retained which may be of service for superficial projectiles or the forceps with long arms for soft organs, such as the lung and the brains. Its relative advantages do not outweigh the inconveniences of such an extraction which is not a good surgical procedure and where the interference of the radiologist however little it may be is always undesirable.

Finally, an argument which dominates all the others is the danger of radiodermatitis inherent to the method and we ask ourselves how Wullyamoz could have written in his pamphlet (p. 24) the following sentence :—" We prefer especially (as a couch for extraction) the type in which the patient is lying on a board and not on webbing. *In this manner the soft rays are stopped by the wood which acts as a filter and protects the patient and the surgeon against all dangers of radiodermatitis.*" We cannot sufficiently protest against that assertion and warn surgeons against it.

Moreover, the bent instruments are very inconvenient in practice. The rectangular forceps grip very badly and can have very little force applied. Finally, what kind of an operation is it in which instruments are blindly sunk into the tissues without one's being able to control the

damage caused ? It may be tolerable in the thenar and hypothenar eminences, but accidents have already been reported in the palm of the hand (injury to the palmar arch).

Nevertheless, especially for the extractions of needles the facilities offered by the various modalities of the new science were such that most of those who have used it have returned to it willingly, and nearly all devised in turn radio-surgical operating tables, the most perfect type of which was suggested by Haret and described by him at the Milan Congress in September 1906 as follows : " The table measures 1 meter long by 60 centimeters wide ; another



197 198 199 200 201

Fig. 197.—The bent forceps are used for searching for the foreign body and are here directed exactly on the foreign body.

Fig. 198.—The extremity of the forceps deviates to the right.

Fig. 199.—The extremity of the forceps deviates to the left.

Fig. 200.—The extremity of the forceps deviates above.

Fig. 201.—The extremity of the forceps deviates below (according to Wullyamoz).

ordinary table can be applied to either end in order to form an operating table of the required length.

" The X-ray apparatus is fixed under the first table on a carriage movable in all directions. The diaphragm is formed by two sheets opaque to X-rays and pierced by two notches, which can be brought near or moved farther. The screen is carried by a vertical support and can, by means of a simple mechanism, be placed above the patient at the will of the surgeon. The aseptic technique is not in any way interfered with by the X-ray examination, as the site of operation can be easily covered with sterilised towels which are transparent to the rays. This device is destined to render great services in the search for foreign bodies."

However, the relative infrequency of the extractions of foreign bodies compared to other operations caused only a few surgeons to adopt the fresh procedure the technical complication of which appeared to them much out of proportion to the results obtainable. Besides the aid of the screen which was used by all the observers presented a number of inconveniences. Those who operated in daylight obtained a very imperfect vision, only enabling them to extract very large bodies, or those situated in the regions of small thickness. Those who operated in a dark chamber were exposed to a series of operative accidents, considerably limiting the usefulness of the method. Those who made the radiologist perform the extraction limited also by this very fact the applications of a process which became not strictly surgical. Finally, all took absolutely insufficient account of the considerable risk of radiodermatitis to which the hands of the surgeons were exposed, which hopelessly condemned the process. It did not therefore come into general use in spite of the fresh efforts made from time to time in France as well as abroad. But none succeeded in removing the defects pointed out, although the fluoroscope with its human eye-glass, an indispensable element for success, had been invented a long time before by Seguy, and reproduced in a diminutive form in the manudiascope of Bouchacourt.

The present war, whilst giving to the surgery of projectiles an importance never thought of previously, should soon restore to honour all the different methods which have been modified and more or less perfected of searching for and extracting them.

M. Mauclaire, for instance, has worked at the solution which consists in operating in the dark.* Although he may have been able to extract projectiles satisfactorily in this manner, he has nevertheless not found any imitators, which can only be too easily understood. †

M. Rechou has happily modified the Wullyamoz process and has justly insisted upon the absolute necessity of a

* See also the excellent series by M. Brindeau, *Bull. soc. chir.* 1915.

† He has, moreover, recently brought his process nearer to ours and adopted the "intermittent" control. See *Soc. chir.*, October 31st, 1916, p. 2425.

preceding localisation, but the interference of the radiologist in the surgical act does not seem to us to be justifiable.

The problem has been studied in several regions at the base, and M. Lobligeois has made use of the assistance which the radiological motor van services could give, which can be perfectly well used for operations under control.

We ourselves, since the creation of special centres, have recognised the incomparable advantages which the control of the screen presented if it were possible to utilise it with simple technique, really surgical and free from inconveniences mentioned. After numerous trials we think we have succeeded in this and we shall describe later in full the manner of procedure which we have adopted.

Our publications and those of the surgeons of the ninth region, who all adopted our process definitely after having tried it, contributed to propagate the method which is to-day in use at most of the bases as well as in the army zone.

Our method of procedure is based upon the collaboration of the surgeon and the radiologist and aims at leaving to each his part, ensuring a genuine surgical operation and saving the surgeon from many errors which are inevitable without adequate radiological evidence.

However, the number of professional radiologists is very small in proportion to the number of radiological installations at work. Certain authors have therefore tried to find a solution in enabling the surgeon to become his own radiologist. They were met by the insurmountable difficulty of providing for one and the same operator a lighting of the field of operation, which is never too perfect, whilst allowing a visual accommodation which darkness alone gives.

We may mention that M. Bergonié has recommended operating in red light, his idea being that since red is the complementary colour of green, the surgeon's eye will accommodate to greater advantage to the green colour of the fluorescent screen.

There is no need to point out the various inconveniences of operation in semi-darkness. This method has an added disadvantage in the difficulty of arresting hæmorrhage from a bleeding surface which can be seen with difficulty. Moreover, the argument in its favour is theoretically inaccurate. The careful research work of Parinaud has shown long ago

that the retinal sensibility increases most rapidly in violet light whilst it increases much more slowly in red. If one really wishes to utilise this idea of operating in monochromatic light of little intensity it will be necessary to use violet light as the monochromatic light without being prejudiced by the fact that violet is not the complement of green, the light of greenish fluorescence of the screen being far from being a single colour, representing on the contrary a composite mixture.

M. Petit (of Château-Thierry) has also used the screen with red light. What is evident from his publications is that one can extract projectiles by this process, with the valuable aid of the screen in spite of the considerable inconvenience experienced during the operation by the red light, extremely tiring in itself, as can be easily proved by a somewhat prolonged stay in a photographic dark room, and which very often causes extreme fatigue and even sickness in the case of certain surgeons.

As to M. Mouchet, he has modified the extraction in red light by wearing a frontal mirror by Clar, because he could not see sufficiently well without it to operate satisfactorily as he himself has admitted. Operating in an artificially lighted room would give him the same advantages without the inconveniences. M. François operates in the same manner, but with a black background, but we think this means complicating matters too far.

We are now going to describe our method in full after having given some general indications with regard to the X-ray outfit (refer also to Chapter IV).

§ 63. **Extraction with the Aid of Intermittent Control.**— The principle of the method which we recommend is the following : At the moment when the surgical operation is to begin the radiologist indicates by means of a point the exact spot corresponding on the skin to the normal ray passing through the projectile.

The operator need therefore only cut down vertically to find the foreign body. If he does not find it at the supposed depth in the gaping and widely separated wound, the surgeon asks again to be given the point where the normal ray corresponding to the projectile ends at the bottom of the wound. Then he resumes his search. The vertical line of the foreign body is hus supplied by the radiologist

as often as required, but while he does so the surgeon stands back and does not expose himself to receive any harmful rays.

Were we the first to employ this method ? This is hardly probable. In view of the danger of the injurious rays the idea naturally occurred to cut off their emission at intervals.

However we have improved the details of our method and made them more precise. We have shown that the operation should not proceed, except during the period when the emission of the rays is suspended. We have succeeded in arranging that the surgeon should at no time be reached by the rays. The radiologist, on the other hand, has only to do work to which he is accustomed and in the course of which he can effectively protect himself if he has learned how to do it.

In fact, we consider it a duty on the part of the surgeon not to expose his hands to the harmful action of the rays.

This precaution is legitimate. The hands of a surgeon who has taken many years to become perfect in his profession belong not only to him and those he calls his own, but also to his hospital service and to his country. The surgeon's hands are his fighting weapons which he has no right to injure uselessly, his duty being to safeguard them as far as possible. It is possible to do so, as we are going to prove hereafter.

THE NECESSARY RADIOLOGICAL INSTRUMENTS.—What is required in order to carry out extractions with the aid of the intermittent control of the screen ?

From the X-ray point of view any outfit which should include a couch with a tube carrier with diaphragm beneath it, movable in all directions, will be suitable if it is capable of producing from 1 to 2 millis in a fairly hard tube (10 to 12 centimeter spark at least). This is a condition which is at present fulfilled by even the most modest installations, and as regards this we simply refer to the conditions given in Chapter IV.

The couch constitutes the most important part of the installation. The ideal one is represented by the metal table so arranged that one end can be quickly tilted up for abdominal operations—such as we have had constructed by the firm of Gallot-Gaiffe and which we have reproduced

in Figs. 68, 69, but the couches by Drault of the Béclère type, by Gallot-Gaiffe of the Belot type, the Rechou type, the tables of the X-ray cars by Gallot-Gaiffe, etc., will also be found to be extremely satisfactory for the work required. Finally, one can—we are not afraid to emphasise it—even do the work perfectly well with a much more rudimentary material, and can improvise almost everywhere much less expensive yet adequate "radiological couches."

A "bonnet" (or a band fluoroscope) will complete the X-ray outfit. It may be an ordinary fluoroscope, and one will do well to provide oneself in that case with a pair of spectacles, the lenses of which are of very dark smoked glass

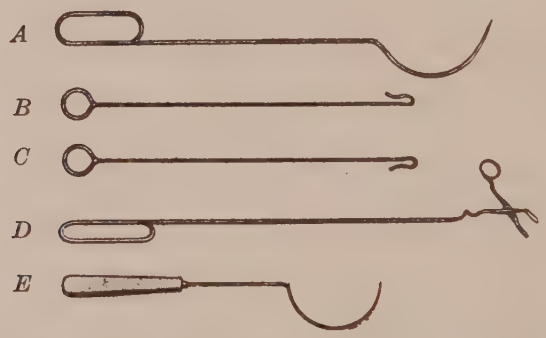


FIG. 202.—The sighting needle (*E*) which we use for the first control. It should be at least 50 centimeters long, so that the hand holding it remains safely outside the cone of rays during the aiming. The large control needle (*A*) *should not be less than forty centimeters* long. The same applies to the two separating hooks (*BC*). A pair of forceps (*D*), mounted on a stem of the same length, will sometimes be useful for sponging the blood in the wound during the control (*Gallot & Co.*).

(see Chapter IV), or, what is simpler and more convenient, with a Dessane eclipse-fluoroscope.

We wish to draw attention to an indispensable precaution which consists in never undertaking an operation with the aid of the intermittent control if one does not have at disposal a *well-trained* spare tube which can replace at once the one which is under the table in case the latter should become useless.

From the surgical point of view, a sighting needle of the kind which is represented by *E* in the figure 202 (Gallot-

Gaiffe), which can easily be replaced by any other suitable instruments, even by a rod of thick iron wire, or still better of brass wire, another one, longer (shown by *A*), easily replaceable by two retracting hooks *BC*, quite simple to improvise and which can, besides, be substituted by several pairs of forceps hooked together, two Ombrédanne separating forceps (Fig. 203), constitute all the special material required. It is advisable to add a hysterometer, suitable for measuring the depth.

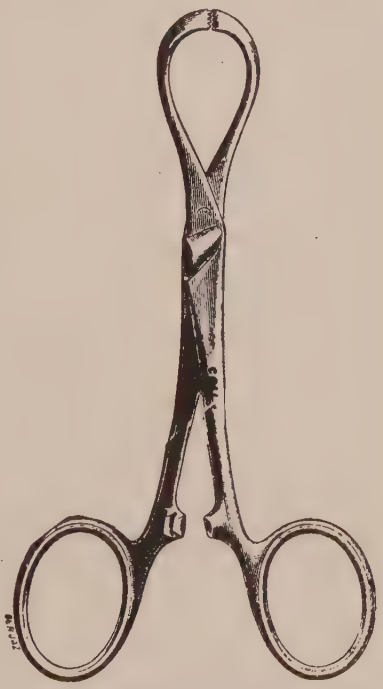


FIG. 203. — Ombrédanne retracting forceps (Collin type). These forceps, which were used long before the war, do not cause the skin to necrose at the points of contact. The Ministry of War supplies them at present to the surgical units.

It will be seen that there is nothing complicated in this outfit, nor anything which cannot be ordinarily procured in all the more important centres at the base as well as in the army zone. Moreover, all the X-ray cars lately mobilised are provided with the Dessane Bonnet and needles of our pattern.

LOCALITY.—In any place where there is no X-ray installation a room in which the operation can be performed is all that is necessary, so that by ordering up the X-ray car with which each army as well as each base is provided (there are generally several cars for each army and two for each base), it should be possible to start to operate with the aid of the intermittent control within an hour.

The problem seems less capable of being solved in a satisfactory manner in the civil establishments, such as especially the Paris hospitals, or in private hospitals

and clinics—at present so frequently converted into auxiliary hospitals. The latter hospitals, although they have in principle no right to any free X-ray supply by the Health Service, have been authorised by a ministerial circular to avail themselves of the X-ray cars free of charge.

As regards the hospitals in which there are often radiological laboratories a long way from the surgical department and where it would be very inconvenient to go in order to operate, it seems that transportable X-ray outfits of the type which one of us had constructed by the firm of Gallot-Gaiffe as described above (§ 14) represent an ideal arrangement *which can be immediately installed in any operating theatre which is provided with electricity.* It seems that this will also be the most perfect arrangement for the hospitals and clinics which are still without X-ray installations and which will ultimately not be able to do without them, since it lends itself admirably to all the screen and X-ray examinations of ordinary practice, whilst it has the advantage of costing relatively little.

One of us was able, without any previous trial, to go to the Salpêtrière and install this outfit in any room, examining the patients and localising their projectiles, then transferring the whole outfit to the operation room of Dr. Gosset, who effected with the greatest facility, with the aid of the intermittent control, the extraction of difficult projectiles which had already been looked for in vain several times.

Therefore, no matter what the conditions may be, it will be easy to adapt them to the very small requirements of our method for effecting extractions with the aid of the intermittent control.

Lighting.—In the case of difficult and deep extractions as well as in the case of any delicate operation the lighting at disposal is never too perfect. The fact that one of the dominant considerations in the choice and establishment of operating theatres is a good lighting supply is enough to show how illogical and contrary to common sense are the methods which place the same surgeon in darkness or semi-darkness when there is really nothing to make this necessary.

The ideal for every surgeon obviously is to operate in *his* operating theatre and *in full daylight.* This ideal can be realised either with a transportable outfit of the kind

which we have described above, which can at will be immediately installed in the theatre if the latter is provided with the electric main supply, or with the necessary X-ray outfit.

In certain cases, however, it will be convenient to operate in the X-ray room specially arranged for that purpose. This is the solution we have adopted at Tours on account of the local arrangements. In similar cases the natural light of the room is generally insufficient for looking for a projectile in a deep wound. We have, moreover, seen Pierre Duval installed in a luxurious hotel and operating in full daylight with a compass, availing himself also of an electric lamp which was directed on to his field of operation. At Tours we do not possess a theatre with top lighting as we are working in a school, and we have therefore thought it most advantageous and simple to look for our projectiles by artificial light. Need we say that it should be as abundant and convenient as possible ? This lighting can be altered at will. Lamp holders with powerful reflectors can be placed in every direction and light at will the field of operation (this being a resource which may frequently be useful for operations carried out in full daylight). Finally, all precautions should be taken to have spare fuses ready so that there may be no lack of illumination for more than a moment in case of their burning out.

In these conditions the artificial light gives the surgeon when he is accustomed to it the same facilities as natural daylight, and allows the radiologist the great advantage of an almost instantaneous receptivity if he takes care not to place himself where the light is strongest.

However, whether one operates in daylight or artificial light, in an operation room with special movable apparatus or with the outfit of a X-ray car in an improvised operation room, or finally in the usual X-ray room, *the procedure will be exactly the same*, the radiologist being receptive and capable of remaining so as we have pointed out.

We will now describe in full our technique at the operation itself.

§ 64. **The Operation with the Aid of the Intermittent Control of the Screen.**—*Preparation of the patient.*—The existence of the projectile having been ascertained, its depth determined from a favourable point of access, its

topographical situation fixed, and the operation decided upon, all the information required is complete, as we have pointed out. The patient has been prepared, as for all surgical operations, under general anæsthesia (ether : Ombrédanne apparatus).

Preparation of the room.—Two tables are prepared : in the centre is the X-ray couch of thin wood covered with aluminium under which is the tube which can be moved in every direction. This is the operation table.

At the side a strong table or a trolley can be used for the early stage of anæsthesia, so that if he makes violent defensive movements at the beginning of the anæsthesia there is no risk of his breaking the thin board of the X-ray couch (Fig. 204).

If cushions are required, these, of course, should consist of bags filled with oats transparent to the rays, not opaque sand-bags.

The anæsthetised patient is placed on the X-ray table in the position indicated by the operator. The latter takes his place at one side opposite the radiologist, who should have in his hands the handles which actuate the movements of the tube shield and the diaphragm. (It is nearly always easy to place the patient in such a position that the respective positions of the surgeon and of the radiologist can be taken up without any hindrance to the course of the operation.)

During this time the radiologist has put on his fluoroscope and allowed his eyes thereby to become accommodated.

Preparation of the region.—The operation zone is disinfected and protected as usual. The four towels being fixed, *a fifth is thrown over the whole.*

Explanation of Fig. 204 (p. 309).—The operating theatre—whether an ordinary theatre or an X-ray room specially arranged for that purpose—has been prepared as usual and according to the surgical requirements of the proposed operation. To the left is *the X-ray couch which will serve as the operating table*, covered with a sterile cloth. To the right the patient is anæsthetised on a solid table in order to protect the X-ray couch from the violent defensive movements which are so frequent at the beginning of the anæsthesia, as the table may be damaged. A trolley on wheels can be used to advantage for the beginning of the anæsthesia. Once properly unconscious the patient is carried to the X-ray couch and placed in position for the operation (from a drawing by J. G. Goulinat).

FIG. 204.

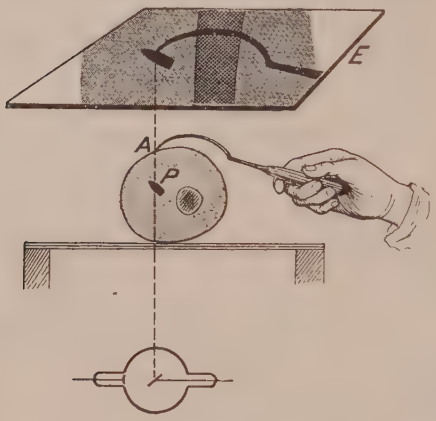
"THE POINT" (Figs. 13, 14, 15).—Whilst the operator and his assistant prepare their instruments the radiologist steps forward. He looks for the projectile, centres it, *then closes his diaphragm to such an extent that he only leaves on his screen an area about the size of a 5-franc piece illuminated with the shadow of the projectile in its centre.*

He is then handed a sterilised pointed rod. We have for some time used a Doyen needle or one similar to it. However, it is as well to use a thicker instrument which would be seen more quickly. Further, after having tried a rod bent at a right angle, according to the Wullyamoz principle, and having ascertained its uselessness, we have adopted, because it catches less in the towels, the thick bent rod pointed at its extremity and mounted on a metal handle, represented by E in the illustration. Its convenience recommends its use, but in its absence any kind of metal instrument may be used instead. No matter which is adopted, the radiologist places its point on the skin (Figs. 205 and 206) in the centre of the image of the projectile (or at any other part of the image, point or base, for instance in the case of a bullet, etc.). Fig. 207 gives an idea of the image which the screen in his fluoroscope will supply if he has just "given the point" to the surgeon over a bullet. He gives the order Stop." The current is cut off.

EXPLANATION OF FIG. 205.—The anæsthetised patient is placed on the X-ray couch in the position for operation, and care has been taken that this is done in such a manner that the side of the couch where the controls are is opposite to the side occupied by the surgeon. The operation region is prepared, asepticised, the towels are placed as usual. *Then a large supplementary towel covers the whole region.* At that moment, *and at that moment only*, the surgeon and his assistants stand aside, the tube is set going, and the radiologist, with his fluoroscope in position, approaches and looks for the foreign body. When he has found and centred it in the middle of his diaphragm reduced as much as possible, the needle previously sterilised shown on Fig. 202 is handed to him, or any other instrument which can serve the same purpose. He places the point of this needle at the level of the point of exit of the normal ray and pricks the skin at that spot (see Fig. *K*). The tube is stopped, the surgeon approaches, raises the fifth towel and makes sure of the situation of the point thus marked. He knows *that a perpendicular dropped from that point to the plane of the table passes through the projectile.* The radiologist retires and the surgeon commences his operation as usual (from a drawing by J. G. Goulinat).

FIG. 205.

The surgeon steps forward, raises the fifth towel, and



FIGS. 206 and 207. — These figures show what occurs when the radiologist "gives the point" to the surgeon at the beginning of the operation, that is to say when he makes the shadow of the projectile (or of a particular point of this projectile, here the middle part) and the shadow of the point of his needle coincide on the screen. In order to do this he keeps the curve of his needle in an almost horizontal plane. He raises it afterwards, making it describe a quarter turn and presses its point slightly into the skin through the sterile towel which covers the operation area. He thus marks, at the last moment, the point of emergence on the skin, at the level of the incision line chosen, of the normal ray passing through the projectile. It is this normal ray, *this imaginary plumb-bob*, by means of which the radiologist will enable the surgeon to find the direction again in subsequent examinations. In this diagram one has assumed that this manœuvre was carried out on a simple screen and without using a diaphragm. In practice this is not so, of course. As soon as the projectile and the needle are seen, the radiologist cuts down his diaphragm as much as possible, and the drawing 207 shows us the image which he obtains on the screen of his fluoroscope.

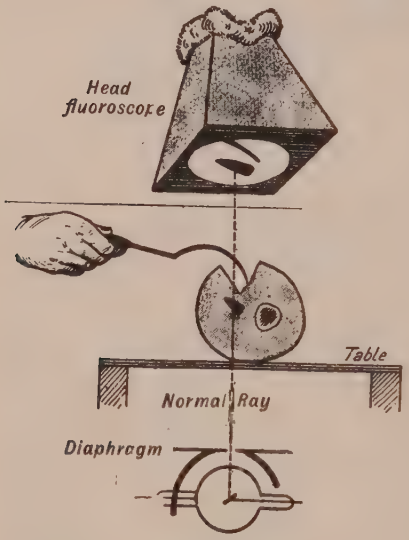
sees through it the point of the needle pressing down the skin.

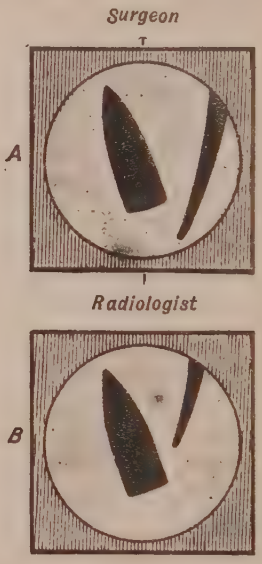
Frequently this puncture is at one or two millimeters from the marked localising point. Again, the distance is often two

EXPLANATION OF FIG. 208.—When coming to the level of a bone and wishing to be sure of passing it at the most suitable point, or when having reached the indicated depth and wishing to know the exact direction in which the projectile is, the surgeon requests the radiologist to give him a control, that is to say, to give him exactly the direction of the normal ray passing through the projectile (from a design by J. G. Goulinat).

FIG. 208.

and even three centimeters out when the position of the patient is not a normal one, or when the lower limb is concerned,





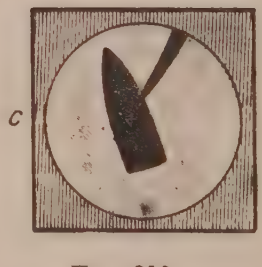


FIG. 210.

FIG. 209.—This diagram shows what occurs when the radiologist makes a control examination. The surgeon has placed the point of his large needle on the point of the wound which he thinks corresponds to the normal ray passing through the projectile. The radiologist looks and ascertains, seeing on his screen the image of the figure 210 *A*, that the point of the needle is badly placed. By his first instruction ("move back two centimeters"), he makes the surgeon bring his point back to the level of the projectile (Fig. 210 *B*). By his second instruction ("one centimeter to the right"), he effects the coincidence of the shadows (Fig. 210 *C*). The point of the needle is on the course of the normal ray passing through the projectile. The surgeon has only to go deeper, following this direction vertically. The instructions given should always be extremely precise and clear and should preferably be given in relation to the position of the surgeon.

which it is very difficult to replace in a position identical to that in which the localising mark was made. These are the cases which most frequently cause the projectile

to be missed with ordinary radiographical methods, although this difference does not hinder our extraction in any way. The surgeon asks for the figure of the depth to be repeated, and makes his incision through the puncture in the skin.

He then proceeds vertically downwards towards the projectile until the required depth is reached or until he reaches the level of the bone. Sometimes the projectile is found at once. This is a rare occurrence in the cases with which we have been concerned.

First Control.—In the ordinary case nothing is seen at the depth stated, and the period of groping for the projectile would commence, or one may be on the level of the bone, when one must proceed carefully. The operator stops, ties any vessels to free the field of operation from the forceps which would interfere with the view of the foreign body, and says to the radiologist: "*A look.*" The surgeon and his assistant move away. A towel is thrown over the patient. This towel is raised by the two corners at the side of the surgeon who can look underneath, whilst the radiologist with his fluoroscope is on the other side above it (Fig. 208). During this manœuvre the wound is kept open by the following means. In the rings of each of the Ombrédanne retracting forceps (Fig. 203) is placed a steel wire 40 centimeters long (Fig. 202, *BC*). By means of that hook the surgeon and his assistant keep the sides of the wound open. The radiologist now makes his second observation. Instantaneously he finds his projectile again in the centre of the luminous spot, and says, "*I see it.*" The operator then comes forward, holding in his right hand a large needle of the same type as the one which was used for the sighting, but 40 centimeters long (Fig. 202, *A*). If necessary, he stops the oozing of the blood by means of forceps carrying a compress, also 40 centimeters long (Fig. 202, *D*).

Then, placing the point of his needle at the bottom of the wound (Fig. 208), he asks: "Is it there?" and displaces it until its shadow coincides on the screen of the radiologist's fluoroscope with that of the projectile (Figs. 209 and 210). The radiologist indicates to him: "Front, back, left, or right," hen "You are there," and "Stop." The tube is cut off. The assistant removes the fifth towel, and

the surgeon, having at the end of his instrument the exact point of the bottom of the wound corresponding to the projectile, proceeds to go deeper.

Second Control.—Very often the projectile is reached at this control. If in proceeding we come upon a viscus, a second even a third control examination may be necessary, which is done in exactly the same manner. Sometimes the surgeon has to ask as many as five or six times, even more, for the "look" of the radiologist in very difficult cases. It matters little, it is only a question of a minute. Frequently also, when a retained bullet has been extracted, for instance, the surgeon will have to ask the radiologist to verify whether the whole of the apparent shadow has disappeared.

This is our procedure. By this method, except in the case of a badly planned operation which necessitates the abandonment of the search on account of a physiologically insurmountable obstacle, an anatomical anomaly, or an accident impossible to foresee, such as a serious collapse from the anæsthetic, the possibility of failure cannot be conceived, seeing that the operator can ask again for the right direction whenever he loses it. Guided step by step, no matter what the position is, the nature, and the size of the projectile he has decided to recover may be, he is sure of extracting it. The moral confidence which this certainty gives should certainly not be neglected.

His only care should therefore be to follow the ray perpendicular to the plane of the table, the ray on the axis of which the foreign body is, and of which the radiologist has marked at the beginning of the operation the imaginary point of issue on the skin in the position chosen. He knows that by following that ray, the direction of which is easy to follow, and which will be demonstrated to him again as often as he likes, he cannot but find the foreign body. Certain interosseous projectiles furnish one of the most simple applications of the method. When placing the shadow of the foreign body in the centre of the ring of a trepan, all that need be done is to bore vertically into the bone in order to find the projectile without any groping for it. We are surprised that this method, especially in the case of the skull—the method having been very well explained before the Surgical Society by Lefort and

Desplats—has not yet been adopted unanimously by surgeons.

Inherent dangers as regards the absorption of the rays.—The intermittent control, carried out according to the technique which we have just explained, does not appreciably lengthen the duration of the operation. A control examination by the radiologist with his fluoroscope does not take longer than putting a compass in place in the course of an operation. Every Monday morning from 9.30 to midday we undertake five difficult extractions. For those who know the time taken up by the dressing of the patient operated upon previously, the quick cleaning, the arrival of the next patient, the time required for the anæsthesia, the average duration of half an hour constitutes what may be called a rapid operation, where the actual operation itself only takes a few minutes.

As to the complications which may follow, they are much more apparent than real, since we have seen that at any radio-surgical centre or at any place possessing a special outfit any kind of operating theatre is immediately available without any other preparation than setting up the X-ray table and operating on it. This means that this method can be applied anywhere where an X-ray equipment is installed, particularly at the front as well as at the base. In civil life, apparatus like that which one of us had made by the firm of Gaiffe and which we have described and shown above (§ 15) will fulfil the same purpose in any kind of hospital service and in any kind of clinic.

Besides, the communications made to the Surgical Society since the beginning of the war by MM. Pierre Delbet, J. L. Faure, Goset, Imbert, R. Lefort, Mauclaire, Potherat, Routier, Schwartz, Soulignoux, Temoin, Toussaint, etc., have shown what interest is shown everywhere in the extraction of projectiles under the control of the screen by reason of the incomparable facilities which it offers. It seemed useful only to determine by experience the exact method to be employed for combined X-ray and surgical manipulation. We think we have succeeded in doing this, and a communication by M. Brin to the Surgical Society shows well the facilities which our procedure has afforded him.

We are now going to show that with the precautions

taken by us, *our method has*, in the case of ordinary extraction of projectiles under the screen, *the advantage of suppressing absolutely all the risks of radiodermatitis.*

In order to avoid this calamity there are two conditions to be observed by the radiologist if he strictly observes the precautions indicated by us; namely, the various means of material protection, on the one hand, and the short times of exposure on the other.

Finally, protection is assured absolutely for the surgeon from the fact that, never being himself exposed to the rays thanks to the very simple arrangements which we have described, or some other similar arrangement, consequently he will never feel any harmful effects.

The radiologist finds himself under the ordinary conditions of a screen examination. The table has an aluminium top. The cryptoscope is provided with a fluorescent screen already rendered very opaque in itself by being covered with lead glass. The radiologist puts on his protecting gloves and must not take them off. He can besides wear if he likes an apron of opaque rubber and also spectacles of lead-glass, but we think these are superfluous.

The tube is protected in such a manner as not to emit lateral rays.

In the first place, the protective shield of lead glass or ebonite mixed with opaque salts only allows the emission of rays in the form of a cone. The adjustable diaphragm attached to it continually restricts that cone during movements of the tube in such a manner that the rays *never spread beyond the fluorescent screen* which is fixed to the bottom of the cryptoscope. Moreover, in our model of X-ray table, lead screens are adapted to all sides so as to protect l erally the legs and feet of the surgeon, radiologist, and even of the anæsthetist. In the case of other types of X-ray tables it is easy to achieve the same results by means or ray proof cloth.

It is of importance to examine carefully all the shields and all the protective glasses and never to forget to put on gloves in order to be protected against dermatitis. This is shown during the war by the example of radiologists, who in their X-ray vans often make an *average* of more than ten screen examinations per day (our colleague Viallet has made 1,097 in four months in our district, and one of

us has sometimes made more than 50 in one day) without any harm to their hands owing to their taking the necessary precautions.

Besides, it must be considered that those radiologists whose names are well known everywhere, and who have suffered extensive damage from the rays, obtained their painful and sometimes terrible lesions in years gone by by using a technique now recognised as essentially dangerous and in which their hands were constantly directly exposed to the rays without the interposition of any protective substance. Moreover, there is in these cases a particular kind of sensitiveness; the smallest quantities of radiation falling on the skin already attacked are sufficient to cause a chronic dermatitis (see Chapter IV).

Take, on the contrary, the case of radiologists, who have come in prolonged proximity with rays since the danger was well known and have taken precautions to interpose opaque substances, and one will find that their hands are free from injury. If any of them shows marked lesions, he has either momentarily neglected the necessary precautions or, being too confident, has used gloves and lead glass insufficiently opaque without first examining their opacity, or has noticed their defects too late. The others are free from injury, although most of them practise radioscopy as we do day after day and are facing a tube working almost every day for several hours. They know now how to take the necessary precautions.

The surgeon benefits in the first place by all these material protections against lateral radiations from the tube.

During the first entry of the radiologist for the "POINT" he stands two meters away from the table, where he cannot be reached in any way by the rays.

During the first control and the following controls he comes somewhat nearer.

Ordinary gloves do not protect the hands. The Mauclaire gloves are no better. Let us presume his hands are bare.

At that moment the sheaf of rays is reduced to the diameter of a 5-franc piece. His hand need not penetrate that cone, since the instrument he handles offers, in the case of the types adopted by us, a minimum length of forty centimeters, and penetration takes place only in the cone of rays.

The hand of the surgeon never receives any rays, since it need not ever be placed in the only path illuminated by the rays. He is therefore essentially safeguarded against any accident. M. de la Palice's axiom which should be emphasised is that the risk run of acquiring dermatitis is absolutely nil. Extraction with the aid of intermittent control presents therefore infinitely greater guarantees than direct extraction by the surgeon, who in the latter method receives on his hands the cone of X-rays, and *we can affirm to all operators that if they will follow our method strictly they will not run any risk whatsoever.*

All those who practised direct extraction under the screen according to the old method are so aware of the extent of the objection that they have tried to find means of protection. For instance Mauclaire has recommended an opaque paste* with which the operator should cover his hands before putting on his rubber gloves. Apart from its great inconvenience, this paste, which it is impossible to apply in an uniform layer and sufficiently thick, does not ensure anything but an illusory protection as the experiences of Lance have shown and as can be easily imagined. Therefore this method in our opinion adds to the danger. Whilst working the operator believes that he is protected and consequently is less afraid of contact with the rays and is therefore more exposed to danger. If one uses gloves which are *really* a protection, their thickness and want of pliability would make it impossible for the wearer to do his work properly.

This exposure of the surgeon's hands to the action of the rays is considered by us to be a fundamental vice of this method, a vice which nothing can at present alter. No matter how much it is persisted in, we, together with Pierre Dellot and other operators, give our warning against it, and we condemn the method most strongly, since we have another method which enables us to escape entirely any risk of dermatitis, whilst giving at least equal, if not better, results.

* We may mention his formula: Thick rubber solution, called by motorists *dis-solution*, 90 grammes; mineral essence, 50 grammes; carbonate of lead, 100 grammes, ground up in a mortar, passed through a silk strainer, and spread out in a layer. Four layers to be applied. Let it dry half an hour between each layer.

There is every advantage in making the professional radiologist look at the screen and avoiding the necessity for the surgeon to make his eyes receptive.

DIFFICULT CASES.—Is it then always easy to extract any kind of foreign body by the method which we recommend ?

The answer is positive when the incision follows a vertical line, in the same direction as the ray going from the projectile to the screen—and negative when the incision has to follow an oblique course in relation to the normal path of rays.

The latter case is illustrated by projectiles situated between the scapula and the costal margin, or by those of the internal iliac fossa arrested near the iliac bone or the sacro-iliac synchondrosis or by those which irritate the roots of the sciatic nerve, etc. These we shall mention further in the following article.

The indicating needle which the surgeon employs may have its extremity apparently situated on the projectile, and may nevertheless be in front or behind it. When we operate, as is generally the case following the vertical line, we are "in the open sky" and the projectile can only be behind the needle, when there is therefore no difficulty. It is not the same if we operate obliquely in the tissues when we are no longer "in the open sky."

In such cases clinical evidence, the careful examination of the X-ray negative and the preceding radioscopic study, together with localising, should furnish enough important information to avoid much groping about.

Manipulations of the instrument very often allow the direction in which the foreign body is situated to be ascertained quite easily.

However, it is sometimes advisable in such cases to possess a method of radioscopic determination of the relative situation in space of the projectile and of the instrument. This can be achieved either by moving the tube and ascertaining thereby whether the projectile or the end of the forceps undergoes the greater displacement, or by employing a double anticathode tube according to a process published by one of us in conjunction with Dauvillier which is fully described at another place in this book (Chapter X).

With this data the radiologist can not only tell the surgeon

that he is on the vertical line with the foreign body, but he can also direct him to go higher or lower on this vertical line until contact with the foreign body is established.

Difficulties relating to the small size of foreign bodies have never stopped us. It has once happened to us that we removed one with the compress when sponging at the junction of an irritated nerve trunk. It was only the X-rays which showed that the body in question had disappeared, and enabled us to find it in the dressings by looking at the compresses used after the operation with the cryptoscope.

THE ADVANTAGES OF OUR METHOD.—To resume, if we compare our method with those different methods of precision which consist in the use of the *compass*, there is no comparison between the two.

The compass leads direct to the foreign body to be extracted, provided that the foreign body has not been displaced since the localisation, and that the indicating marks are strictly unaltered. We have already mentioned a certain number of cases in which we have extracted projectiles which would certainly have been missed with the compass. We have explained the reason for this (§ 61).

The method which regulates the compasses, no matter of what kind, is a particular example of the *general method of intermittent control*. The operation takes place, in full daylight, without the operator ever receiving on his hands any X-rays. Then, from time to time, once at the beginning of the exploration and as many times as necessary during its progress, the surgeon asks again for confirmation as to his position. This information is given *immediately* with our method, the radiologist telling the operator where the projectile *is at any particular moment*. In extraction with the compass this same information is given indirectly in the form of a *record* made by a measuring apparatus, the record in itself being exact, if the conditions of relationship of the apparatus to the body of the patient (which are easily altered) have not changed. This establishes the essential inferiority of *intermittent control by a recording apparatus* to *direct intermittent control of the screen*.

If we now compare our method of direct extraction under

the screen we find that it has a certain number of advantages of capital importance.

(1) *For the surgeon.*—Extraction under the screen exposes the hands of the surgeon to the harmful action of the rays more or less, and in practice rather more than less. In our process his hands never come nearer than forty centimeters to the path of the rays. This means that he is ENTIRELY protected against the accident of dermatitis.

(2) *For the radiologist.*—In the course of his investigations his eyes are protected by a cryptoscope provided with lead glass, his hand is protected by heavy lead gloves, which are practically impermeable to the rays. Consequently no greater field for harm from the rays is offered than occurs in the course of any radioscopic examination whatever, during which he knows how to protect himself effectively if he has taken the necessary precautions mentioned above.

(3) *For the patient.*—Intermittent control of the screen definitely exposes the patient for less time to the action of the rays than processes of direct extraction under the screen. The matter would be of small importance if he were submitted once only to the action of the rays, but it is not rare to find men who have already been radiographed about ten times. Consequently, the time of exposure is not a matter of indifference. Let us point out also the following material errors: Substitution of plates, of records or multiple wounds, mistakes of side, etc., are always possible in clinics however well organised, but are always very regrettable, and are only avoided by collaboration with the screen.

On the other hand, of greater importance is the *absolute certainty* of carrying out the extraction of the projectile successfully—and this is not a negligible factor for the patient. On our arrival in the ninth district there were many men who refused to submit to the extraction of projectiles which had previously been *missed* in the course of previous attempts. Since our results have become known, our difficulty is rather not to accede to the wishes of wounded men who want to get rid of their projectiles, as they are certain that an extraction undertaken by us will be successfully carried out.

Even for the surgeon that certainty, as we have said

before, constitutes a moral factor of considerable importance.

Criticisms.—If we consider now the criticisms levelled against our method by certain operators, none of whom have taken the trouble to come and see us operate, what do we find ? Is it that the apparatus is complicated ?

We have already replied to this previously in advance, having shown, on the contrary, that *everywhere*, both at the front as well as at the base, it is easy to operate with the aid of intermittent control and in the absence of any fixed installation, by using the travelling X-ray cars.

M. Pochas has told us that we cannot remain aseptic. If he had come to see us he would have changed his mind and our results are there to reply to him.

What we have described in full may seem a complex method. In practice it is simplicity itself.

It has been said several times that our method requires the collaboration of a medical man who is a professional radiologist. This is true if one wants to obtain the maximum benefit, but is not a good surgeon required in order to carry through successfully any delicate operation ? Only the united efforts of two real specialists will give the most perfect result, and every diminution in value of one of these two factors will diminish the total value. The real outstanding reproach which can be in our opinion put forward, is the temptation to extract too many projectiles in the absence of definite indications for doing so, as one might easily be inclined to do on account of the certainty of success with the aid of intermittent control.

Numerous surgeons, however, have come to see us operate and others have tried our method themselves, and we think all of them have taken away with them the conviction that it really is a method of *certainty*, not involving, for the operator, *any risk whatever* of contact with the harmful rays, which is the object we have aimed at. The fact that all have recognised the value of it, and that such operators as H. Barnsby, Brin. Dujarrier, Duroux, Pierre Duval, A. Gosset, Labey, Lapevre, Ch. Martin, Mornard, Robineau, Vouzelle, etc., have accepted the principle, affords the best reply to all criticisms. Finally, there are figures to support our assertions.

Statistics.—We have already reported to the Surgical

Society at the meeting on November 3rd, 1915, a complete and consecutive series of 110 attempted extractions of projectiles with 110 successes, these projectiles representing 100 patients. On February 16th, 1916, we presented to the same society a fresh series of 100 wounded (109 projectiles) with 109 successes. That is 100% on 200 wounded and 219 projectiles. In this series we count as one projectile groups of projectiles situated in the same region which can be reached by a single incision (by counting them separately the total would have been 319 projectiles extracted). We arrive to-day at a total of 310 patients with 330 projectiles and 330 successes, viz. 100% of successes in 330 consecutive extractions. We interrupted one operation on account of formidable hæmorrhage of the main iliac vein —probably. The arrest of hæmorrhage was difficult, and we preferred to take out the bullet a little while after at a second operation. We do not think that a similar result has ever been obtained before our time, and we doubt very much that it could be obtained otherwise than with the aid of the intermittent control of the screen for a similar series of projectiles of like difficulty.

If we consider the results obtained by those who have adopted our me hod we find that they fully confirm its value.

Dr. H. Barnsby has reported to the Surgical Society that after a series of extractions in which the proportion of non-success was 20% he has been able to remove *without any failure* 63 consecutive projectiles according to our method.

He has since come back, having been with the armies, and after having made a series of extractions, and being exceptionally fortunate with the Hirtz compass aided by our screen control, he has been good enough to communicate to us the list of extractions made by him with the collaboration of Dr. A. Barnsby in a surgical ambulance at the front, *without one failure*, from June 22nd to August 14th, 1916. It includes 100 extractions of projectiles (several interosseous, intercranial, pulmonary, etc.).

Dr. H. Brin forwarded to the Surgical Society in March 1914 the list of 117 extractions executed by him in collaboration with one of us and which included a number of projectiles of an exceptional difficulty. There was only

one failure, due to the stoppage of the operation *on account of a chloroform accident* at the moment when he felt the projectile, which was moreover easily extracted a little later under local anæsthesia.

MM. Beaudouin, Boureau, Belgrand, Cheve, Duroux, Lapeyre, Ch. Martin, Morel, Mornand, Perrin, have, with the collaboration of M. Dauneau, Dr. Fleig, Dr. Menuet, Dr. Homme, M. Taveneau, or one of us, removed altogether 975 projectiles without a single failure.

Dr. Labey, together with Dr. Fleig, M. Malaquin, or one of us, has extracted a series of 120 projectiles ; M. Robineau a series of 160 with M. Fleig and one of us. Two failures in that number : One was a piece of shrapnel, situated behind the bifurcation of the iliac vessels with a widely spread arterio-venous aneurism, which produced such difficulties in arresting hæmorrhage that the projectile, though felt with the finger, was abandoned. The other case was that of an intrapulmonary projectile, the record of which is given in the next chapter.

There is thus a series of more than 1,300 *extractions of projectiles for which we have to record only* 3 *failures, viz.* 0·3 %. *No comment is needed on such a total.*

CHAPTER XIV

SPECIAL PECULIARITIES OF CERTAIN REGIONS

Indications for operation and the *route of access* vary essentially according to the region of the body in which the surgeon intends to perform the extraction of a projectile.

We have already pointed out the advisability of considering this extraction to be definitely shown when the dangers and operative destruction of tissue necessary are less than the pain suffered by the patient. We are going to point out the dangers and injuries to tissue for every region in particular.

On the other hand, the route of access is based on the topographical anatomy of the region where the projectile has its seat. In a general manner the problem to be solved before undertaking an extraction consists *in so arranging matters that the surgical route of access coincides with the normal ray passing vertically through the projectile.*

We have already explained (see Chapter III) what should be understood by the normal ray. It is practically the pencil of X-rays given off from the anticathode and passing through the centre of the diaphragm attached to the tube, perpendicularly to the plane of that diaphragm. Apart from a few exceptional cases which we shall mention, the tube, when performing extractions with the aid of intermittent control, is arranged under the operating table. The diaphragm is placed directly above the tube, the normal ray is, and therefore remains, vertical and perpendicular to the plane of the table, no matter what displacements are carried out with the tube in the horizontal plane subjacent and parallel to the plane of the table and in which the stage bearing the tube moves (see Chapter III). These displacements have the purpose of causing this vertical normal ray to pass through the pro-

jectile, that being so it is sufficient to cause the way of surgical access to coincide with this vertical normal ray in order to solve the problem.* As regards the radiological details we refer the reader to Chapter XI, which is devoted to the anatomical localisation of projectiles in various regions.

We cannot think here of giving a complete study of the extraction of projectiles belonging to each region, as we should thereby entirely exceed the object of this work. We shall give essentially *practical* indications resulting from *our own personal experience.*

I—Head and Neck

§ 65. **Intracranial Projectiles.**—Extraction is necessary whenever there are signs of abscess of the brain or convulsions, but if the trouble is reduced to chronic headache with tendency to vertigo, the problem is more difficult to solve, and the indications for extraction are still under discussion.

As far as we are concerned, following the advice of our colleague Clovis Vincent, we attach great importance to the result of lumbar puncture, and if the case presents moderate operative difficulty we intervene if a definite lymphocytosis is ascertained in the liquid. We think it is too late to wait for operation until signs of meningitis appear, and that hyperleucocytosis of the cerebro-spinal fluid is a sufficiently alarming symptom for justifying operation.

The route of access will be chosen according to the situation of the projectile. Nevertheless, we shall remember the comparative lack of risk with which we can explore through the frontal lobes.

The regions to be avoided are :

(1) The large sinuses—*i.e.* the superior longitudinal, lateral

* In those exceptional cases when it is very difficult, almost impossible, to follow the direction of the normal ray, operation with the aid of the control of the rays is rendered somewhat less easy and rapid. Still it is possible however to obtain its full value. It will then suffice to examine the region of the body in the course of the operation in two different directions in order to guide the surgeon exactly. Finally, if that manœuvre cannot be realised, it will still be possible, by moving the tube and making controls in two different positions of the tube, to obtain data sufficient to guide the surgeon's instrument, although this may cause some probing.

and the torcular Herophyli. It is advisable not to allow the trephine opening to approach nearer than two centimeters to the middle line;

(2) The cerebral ventricles. The fact of having to open a ventricular cavity singularly increases the seriousness of

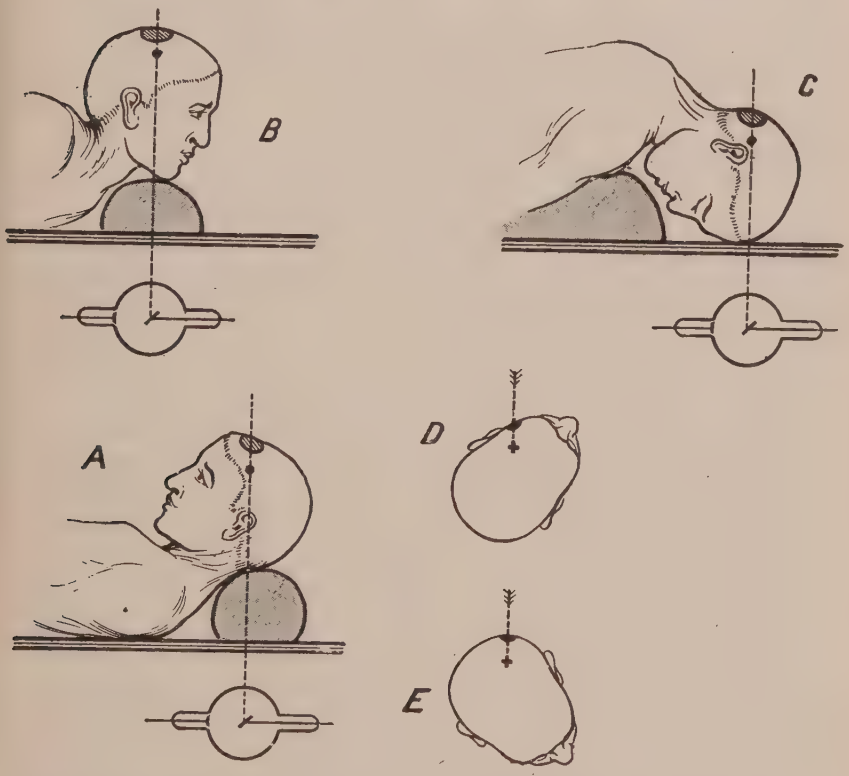


FIG. 211.—The drawings *A*, *B*, *C* indicate the movement of flexion or extension of the head which will allow the normal ray, which passes through the projectile, to emerge exactly at that point on the cranial surface selected as the centre for the trephine opening. The drawings *D* and *E* show the movements of *rotation* of the head necessary for placing it in the required position.

the operation, and we try carefully to avoid it, if possible.

The method followed by us is perfectly definite. We operate once only, as we consider the operation in two stages to be a useless complication.

The projectile to be extracted having been roughly

localised by an examination in two directions (or better still by two radiographs at right angles), we demonstrate to the radiologist the exact point on the head where we are going to operate. He assures himself that it is possible to cause the normal ray traversing the projectile to pass through that point. Then he determines exactly its depth on the vertical line in question from the selected point by the localisation process to which he is accustomed (we use the radiobathymeter).

As this determination requires the passage of a normal ray, both through the projectile and through the point required by the surgeon, it follows from this inevitably that this position can be obtained. It is quite easy to find it again, since the whole of the factors are known. At the moment of operation, the patient being anæsthetised and placed approximately in position, an assistant holds the head, which can be steadied by wadding or ball cushions filled with oats.

The radiologist instructs this assistant as to any further displacements of the head, movements of rotation on the one part, or of deflection on the other part, or, if necessary, he himself does this to save time (of course, with all necessary aseptic precautions), thus arranging the head in good position, until the image of the projectile is projected on the required point of attack.*

He then indicates that spot once more to the surgeon with the point of a special needle. The operator then makes at that point (after incising a portion of the scalp) a trephine ring of twenty millimeters, and one only. In the event of hesitation or of slipping of the head, etc., it is easy to put the trephine ring in position and to make the radiologist verify that the shadow of the projectile is projected exactly on the centre of that ring before making the hole. After the trephining has been completed, the surgeon asks the radiologist to look. He finds the projectile again, and, if necessary, *causes the position of the head to change until the image of the projectile is projected exactly in the centre of the* trephine hole. The tube is stopped. Then the dura mater is cut. The blade of the bistoury is sunk

* We refer to that which we said in Chapter XI. The use of a metal ring, especially the ring forceps, is often to be recommended in order to facilitate this arrangement.

vertically to the depth required, which has been previously measured off on the blade of the instrument. Sometimes its point brushes the projectile, but this matters little.

If the foreign body is magnetic, the pole of a continuous electro-magnet is sunk vertically in the place of the blade. When the desired depth has been reached, a shock indicates that contact has just been established. It is sufficient then to withdraw the pole of the magnet slowly to take out the projectile. Sometimes the foreign body sticks half way. The pole is plunged in again exactly as in its first passage, finds the projectile again nearer than before, and takes it out again, completely or incompletely.

Two or three of these in-and-out movements will always extract a magnetic foreign body. The contact is announced each time by a click which is heard even by the assistants. We have in this manner removed in the presence of Inspector-General Février a bullet which was seated almost in the centre of the brain (96 millimeters from the base, 132 from the vertex).

If the foreign body is not magnetic, a pair of bullet-extracting forceps are sunk vertically to the indicated depth, previously recorded on its arms and marked by a scratch. When this mark is at the level of the scalp, we open the forceps a known distance, just sufficient according to the size of the projectile; we then thrust down one centimeter further and close the forceps again, the ends of which grip the foreign body.

It would seem that by proceeding in this manner there could not be any cause for a mistake if the head had not moved. In fact we have always effected our extractions of intracerebral projectiles without any difficulty. It has happened to us only once, in the case of a very small splinter, which measured less than five millimeters in its largest diameter, that we did not immediately find the projectile shown by the screen however to be always at the same point in the centre of the trephine hole. On inclining the head and placing it sideways, this unforeseen difficulty was explained. The projectile had emerged with a drop of blood behind the blade of the bistoury, and had fallen down outside, but the operator had not noticed this. By a singular accident it had stuck on the skin of the occipital region, exactly at the point where the normal

ray emerged from the centre of the hole. As the figure shows, it appeared on the screen as if it had not changed its place and had not been extracted. Any other method would have led to a multiplication of useless attempts in the neighbourhood, and only increased the traumatism, the matter finally being abandoned in desperation, the operator being certain that the projectile had not been extracted. As it turned out, it was sufficient to incline the head in profile in order to see that the splinter was no more in its place. By opening the diaphragm more it was soon ascertained, that far from having perhaps sunk in deeper after the introduction of the bistoury or the magnet, as we imagined for a moment, it had really been already extracted.

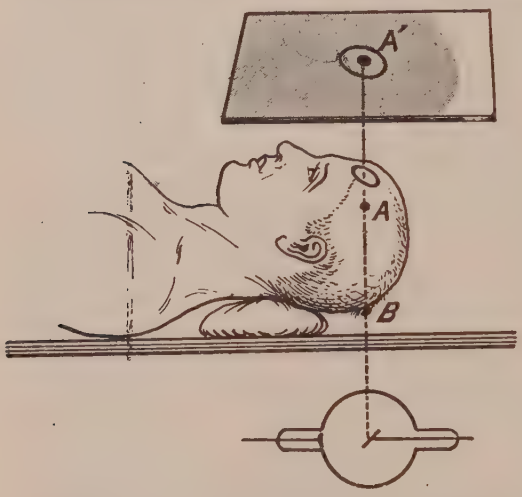


FIG. 212.—The shell splinter *A*, the shadow of which was projected at *A* on the screen, in the centre of the trephining orifice, was extracted without being noticed, and, falling out of the wound, slipped along the shaven skull, being carried along by the blood, finally stopping at *B* in a tuft of hair which had been left by the razor. However, at that point, the shadow was thrown through the same point as *A* on the screen and was therefore, apparently, in the centre of the trephine orifice.

In all difficult cases this procedure of inclining the head shows the situation of the projectile and the end of the instrument in two directions at right angles, and enables therefore any mistake in the position of the forceps or magnet to be corrected immediately. The rapidity, simplicity, and security of the method which we have just described, and which Desplats and Le Fort have already rightly recommended to the Surgical Society, appear to us to render other methods superfluous. It seems also that

all who have tried it have found it suitable, seeing that M. Rouvillois, who recommended at first the use of a telephonic probe, has become converted to operation under screen control, and M. Hirtz himself, after having operated with M. Barnsby, has recently published an article in which he describes an adaptation of his compass to this extraction under screen control. We are however of opinion that his device presents a complication which does not seem indispensable. If one wants to operate with any compass whatever, and with that of M. Hirtz in particular, nothing prevents it being done on the X-ray table and in that case, if the foreign body is not reached at once, the simple method explained by us can be employed.* The same applies, of course, to cases of projectiles in fresh wounds of the skull, when one will naturally utilise the opening made by the wound unless there are exceptional indications against doing so.

PROJECTILES OF THE ORBIT AND EYEBALL.—Great care and moderation are needed as regards the extraction of projectiles in the orbit. Pain, diminution of vision by compression of the optic nerve, and appearances indicating the possibility of sympathetic ophthalmia are evidently very important reasons for extraction. However, no matter what operative method is followed, whether above or below the eyeball, it must be considered, if the eyeball is sound and sight has been preserved, that the extraction of a projectile from the orbit seriously exposes to injury the nerves supplying the muscles of the globe, thus leading to paralysis of some of these muscles, strabismus, and diplopia. These difficulties should be carefully weighed in dealing with projectiles embedded in the orbit.

Our method of extraction will however be of the greatest help in that difficult region, enabling the operator to find projectiles searched in vain by other methods, which fact one of us in conjunction with F. Terrien † has been able to ascertain by operating successfully on patients who had already been subjected to as many as four operations

* Le Fort, *Soc. chir.*, July 27th, 1915; *Rouvillois*, August 17th, 1915, and February 1st, 1916. Abadie, January 11th, 1916. Hirtz, *Presse médicale*, 1916. The ingenious apparatus by MM. Tanton and Viellet is also very complex (*Soc. chir.*, October 1916).

† F. Terrien and R. Ledoux-Lebard, *Ann. opht.*, 1916.

PLATE VI

Fig. 1.—Antero-posterior radiograph of the lumbar spine. A shrapnel bullet is seen throwing its shadow between the third and fourth lumbar vertebræ, the bodies of which appear to be broken. A shadow of new bone formation is seen surrounding the projectile between the vertebræ. The bullet is probably included in the newly formed osseous shell and is lodged between the two vertebræ (see fig. 3).

Fig. 2.—Radiograph of the right half of the thorax as seen from the front. The shadow of a shrapnel bullet is present at the level of the eighth rib. At the periphery of the lung can be distinguished two encysted areas of localised pyo-pneumothorax. A probe has been introduced in the lower area. Notice the diminished transparency of the lung in the area surrounding the projectile.

Fig. 3.—This lateral radiograph of the lumbar column as seen from the right side confirms the conclusions established in fig. 1, which have, besides, been verified on operation. The projectile was removed by Dr. H. Brin with the aid of intermittent control, the patient having been placed at the time in the lateral position lying down.

Fig. 4.—Radiograph of the right ilium as seen from behind. A shell splinter has perforated the bone (the perforation can be clearly seen). It was probably partly embedded in the bone, as can be presumed on account of the area of decalcification which is visible round its lower half. One should be careful not to mistake for bony perforations those transparent areas due to bubbles of gas in the intestines, which are frequently so apparent in the pelvic region.

PLATE VI

FIG. 1

FIG. 2

FIG. 3

FIG. 4

without result. Let us repeat here that all projectiles of the orbit, which can be removed by surgery, will be rendered visible, especially with the use of the Dessane fluoroscope. In difficult cases advantage will be taken, as for the skull, of examination in two positions, face and profile, during the operation, in order to guide the operator.

As to projectiles in the eyeball itself, we have remarked that they are almost the only projectiles which may not be amenable to localisation nor to radioscopical examination. Indications for their extraction may then exist for such small splinters that they almost escape the eye and can only be removed by the giant electro-magnet. Their extraction requires a method and knowledge of so special a character that we can only mention it here in passing, and we refer in this connection to the special works on the subject.

Projectiles in the Maxillary Sinus.—The only interesting detail which we have noticed in this respect is that we have often found pieces of metal embedded in bony shell, when we were very much inclined to think that they were near the roof of the maxillary sinus surrounded by soft tissues.

Projectiles in the Pterygoid and Maxillary-pharyngeal Regions.—In these cases one must absolutely avoid any external scar, and try to operate through the mouth, availing oneself of screen control and of examination in two different planes during the operation, the position of the projectile having been previously studied and measured. One of us has thus extracted, with Ch. Martin (of Agners), several difficult projectiles from the pterygoid fossa.

However, we do not recommend this method for the maxillary-pharyngeal region, especially when there is the slightest doubt as regards the relations of the projectile to the bone. In conjunction with Dr. Labey, one of us once observed during an exploration for a difficult projectile of the pharyngeal region, the disappearance of the projectile, the shadow of which, quite clear at first, was no longer seen on the screen. Before examining the whole region with an open diaphragm, the splinter of metal was noticed in the œsophagus; it had been liberated and swallowed.

Projectiles of the Carotid Region.—We have removed metal fragments in contact with the blood vessels

and pneumogastric nerve. This is a region where the surgeon should be able to see especially clearly in the course of operation. It is also a region in which compasses must be applied very carefully, any displacement of the head having a considerable influence on the situation of the projectile in relation to the fixed measuring points, which can only be taken at a sufficiently great distance and on parts of the body subject to movements. The necessity of dissecting out the blood vessels exposes also the position of the required metal fragment. That is to say, that there is almost a necessity for control of the screen in order to carry out an extraction in that region with certainty and safety.

The same remarks apply to the projectiles situated near, or in contact with, the œsophagus.

II—Thorax

We shall not say anything further about projectiles in the walls of the thorax, as these do not require any special remarks.

§ 66. **Intrapulmonary Projectiles.**—The extraction of intrapulmonary projectiles is important on account of a statement, the credit for which goes to Marion, who has thrown much light on the subject since the beginning of the war. That is—the little importance to be attached to the presence of a pneumothorax and the uselessness, already pointed out by Bazy, of the apparatus for introducing excessive or diminished pressure of air into the lungs during operation.

All intrapulmonary projectiles should not be removed. Here also it is necessary that the trouble resulting from their presence should at least be equivalent to the operative danger and inevitable damage caused through operation.

Amongst the complications we have met with, and which we considered were indications for extraction, we must mention hæmoptysis, abscess formation, with fever and purulent expectoration and painful dyspnœa. Our colleague Denéchau, Médecin de Secteur, has observed four cases of pulmonary tuberculosis at the place where pieces of metal were imbedded. The danger of witnessing an outbreak of future bronchopneumonia on the occasion of a

slight attack of bronchitis, or influenza for instance, seems to us an argument not without value, but has not yet been supported by a sufficient number of exact facts. This consideration would lead to the extraction of all pulmonary projectiles without exception—a procedure which we do not advise. The principal contra-indications to extraction are in our opinion: the smallness of the projectile (corn grains) and its situation at the hilus or its immediate neighbourhood. This region is particularly dangerous—more on account of the numerous *ramifications*

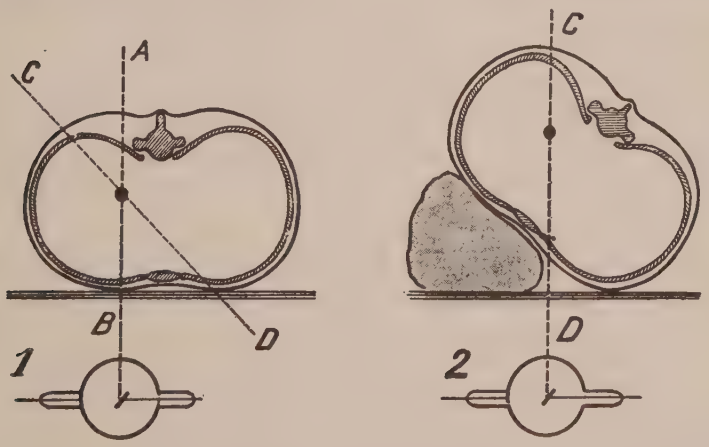


FIG. 213.—By varying the angle of the patient's body the normal ray can be made to emerge at will through any point chosen on the thoracic wall as the route of access.

of the vagus nerve (Leriche), than by reason of the grouping together of big vessels.

The route of access is indicated by the depth of the projectile in relation to various points of the thorax.

When operating from the back as well as from the front one should keep away as far as possible from the middle line. Thus will be avoided any difficulties caused by the transverse processes and in front by the internal mammary artery. In such cases a cushion filled with oats (not with sand, which would be opaque to the rays) can be placed under the lateral wall of the thorax on the injured side so that the normal ray emerges a little more to the outside.

Several times we have effected our extractions through

an intercostal space without interfering with the ribs at all, but even if the depth of the projectile was considerable we have nearly always been able to avoid costal resection. We cut the rib near the chondro-costal junction. The rib, widely freed at its internal part, is seized, fractured by the hand as far out as possible, and kept raised by a retractor. The space thus obtained is very large especially if a narrow ball cushion causes the thorax to protrude forward. When the extraction is over the rib is turned down like a hinge and fixed at the near end by a catgut stitch passed through it with a perforator. This method gives us the best results.

The approach to the pleura is quite different according to whether it is free or adherent.

When the pleura is free the extraction is mere child's play. Thus, after the serous layer is opened, the examining finger feels whether there are adhesions. If they are soft and give way easily without bleeding it is best to free them first.

In this first case the lung can be easily brought outside through the thoracic gap. Then look for the projectile which can be very well felt by palpation, ask the radiologist to verify, if necessary, whether what is pointed out to him is really the metallic foreign body looked for. All this is easy. We cut the parenchyma at the spot at which we can most easily come down on the projectile, which is generally removed with a certain amount of effort, as the shell splinters often adhere to the pulmonary tissues. In some cases they are included in a small cavity full of thick fluid from which they are easily extracted. When the projectile has been removed, the wound in the lung bleeds only a little or not at all when the lung is free from adhesions. We therefore consider it is generally unnecessary to insert a suture. We have only done it once, and we have never had any trouble with our other extractions in the case of a free pleura. In fact, when the lung is free from adhesions, the retraction of the parenchyma is sufficient to stop any bleeding. Pneumothorax is evidently a very favourable condition for preventing hæmorrhage.

Matters are quite different when the pleura presents extensive adhesions which resist and bleed when one tries to liberate them. This, unfortunately, happens very often according to our records with projectiles retained

for a long time. It is then necessary to create gradually a way by means of blunt instruments following the vertical ray, asking if necessary the radiologist to give the exact point when the depth indicated by localisation has been reached.

But the opening made bleeds frequently, because the lung cannot retract. We leave there for forty-eight hours a tent to arrest the bleeding if the oozing is abundant.

The prognosis is very different according to the condition of the pleura. The extraction in the free pleura has never given us the slightest trouble.

In cases of adherent pleura we have recorded two deaths. One occurred slowly in the case of a patient who had a large hæmothorax. The pleura was very adherent, but only at a few points. It was not possible to free it. The free points allowed the formation of a large effusion which became infected and which we had to open at its most dependent part, like an empyæma. The patient succumbed a few days afterwards from embolus.

It was in consequence of this large hæmothorax that we decided to leave in position a hæmostatic tent and we have never seen this accident happen again. In the case of an officer we removed a rifle bullet very near the hilus, because in the four months during which the projectile was embedded he had frequent hæmoptysis. The pleura was entirely adherent. After extraction the hæmorrhage was abundant and we inserted a tent. When it was taken out at the end of forty-eight hours there was again an abundant flow of blood, appearing to come from the site where the bullet had been. We replaced the tent, leaving it twelve days, soaking it every day with a styptic. The tent then came out very easily without a drop of blood and the patient was cured.

The second patient whom we lost after an extraction with an adherent lung succumbed to a pneumonia which started in the affected lung and spread to the opposite side.

This proportion of the number of those operated upon by us is not very great, since we have made forty-seven extractions of pulmonary projectiles. However, we wish to point out that these two accidents and all the lesser adverse symptoms, slight hæmothorax, temperature persisting about eight days, slight pulmonary congestion, etc., have *all*

occurred in cases where the lung was adherent, but never when the lung was free or liberated.

The prognosis is therefore very different in the two cases.

It need hardly be pointed out that on account of its mobility, of the total or partial retraction to which it is subject at the moment of opening the pleura, the lung is one of the organs in which the compasses may lead to grave miscalculations in the search of foreign bodies, the extraction of which is only really certain and easy when the control of the screen is made use of.

An intrapulmonary projectile which was rather large, measuring 6·5 cm. by 3·5 cm., was searched for unsuccessfully three times, at least once by a surgeon of the Paris hospitals, before it was extracted by us. In spite of its size it could not be felt with the finger in a lung with a lardaceous area and bands of sclerosis. Besides, have we not ourselves seen *Marion* himself give up the extraction of a bullet in a free lung which had retracted ? (Marion, in *Thèse Weber*, p. 87).

However, the relative safety of the pulmonary operations and certainty of operative success afforded by the radioscopic control do not seem to us to justify the adoption as a general method of extractions by forceps under the control of the screen, after simple cutaneo-muscular deep incision, such as practised by M. Petit de la Villéon.

They can certainly be carried out most frequently without difficulty and even very easily and with the certainty of not missing the projectile when a double anticathode tube is employed, according to the method described by one of us with A. Dauvillier (see above Chapter X). They provide for the person operated upon, in favourable cases, a minimum of shock and a rapid cure, but they seem to leave room for too many and too serious possibilities of error for them not to be taken into serious consideration, as M. Silhol has rightly pointed out before the Surgical Society.

In the first place, in such a narrow cavity without the use of a double anticathode tube, the grasping of the projectile may sometimes prove extremely difficult and necessitate serious laceration of the lung. Then if we exclude this procedure in the hilus region rightly contraindicated by the author, can one ever be sure of withdrawing without

leaving a bleeding point ? One of us, operating with Labey in the recognised method for a projectile at a small depth (four centimeters) in an absolutely free lung experienced a troublesome hæmorrhage which was only arrested by ligature.*

Moreover what becomes of the small septic foci the contents of which are set free in the lung ?

We think therefore that one should not avail oneself of this method unless the cause is perfectly well known, and we must ascertain by a frequent and particularly exact clinical and radioscopical examination the condition of the lung and of the pleura.

PROJECTILES IN THE POSTERIOR MEDIASTINUM.—As a general rule, we think that this is a region where one should not extract projectiles.

We have only once done so with success. The case was one of a bullet in the dorsal region to which the descending aorta communicated its pulsation. We cut two ribs at the level of the extremity of the transverse processes and displaced them outwards. The hand inserted into the pleural cavity felt the pulsating projectile at the angle of the vertebral column, separated from the aorta only by a small amount of soft parts. We were able to disengage the bullet and to extract it, but the venous plexus gave rise to a rather copious hæmorrhage. We had to leave a tent in position for forty-eight hours.

PROJECTILES IN THE ANTERIOR MEDIASTINUM.—We have observed a certain number of shell fragments pulsating freely which we have localised under the arch of the aorta, against or in the walls of the heart (see Chapter XI). As

* We have tried to follow step by step the method of M. Petit de la Villéon. It seemed to us that in practice the surgeon put his hands if not in contact yet at a disquieting proximity to the sheaf of harmful rays. Moreover, in the course of one of these efforts we attempted to extract a shell splinter of medium size: we saw it, we established contact with it with our forceps, but it was quite impossible for us to grasp it, although each of us tried to do it in turn.

We had to finish this extraction by our ordinary method, making a temporary resection of one rib. The patient made a good recovery.

Nevertheless it follows that not only may it be difficult to obtain contact with the projectile, but also the grasping of it may be impossible even to operators who have had some experience.

the trouble was insignificant, we did not think it advisable to operate except in three cases.

In one case the projectile was a large shell splinter two centimeters long lying in front of the pericardium It was easy to extract it directly.

In the two other cases rifle bullets were present to which the impulse of the aorta or of the heart was strongly communicated, very near the anterior middle line, at a depth of about seven and five centimeters, one at the level of the second rib, and the other at the level of the fifth.

In both these cases we made a pleurotomy displacing one rib outwards. The hand inserted into the pleural cavity felt the projectile in the mediastinum separated from the finger by a small thickness of soft parts. By separating well we were able, by means of a grooved probe, to disengage one of the ends of the bullet, which the electromagnet brought outside, without a drop of blood. The first must have been near the aorta, the second near the pericardium. Cure without incidents in the three cases.

PROJECTILES IN THE HEART.—We have not removed since the war any projectile included in the walls of the heart itself, although we have seen several of them. There are, in fact, two regions where the extraction would almost certainly mean death. These are the auricles on the one part, and the groove of the coronary arteries on the other part. One of us published some years ago before the Surgical Society details of a death at the end of eight days of a female patient from whom a sharp needle in the anterior coronary was extracted. Only in the ventricular wall in this region can operation be risked with a chance of success. It is thus only when the projectile is in this situation or when the projectile is free in the ventricle that we should commence to discuss the advisability of an extraction which might sometimes be successful.*

PROJECTILES IN THE DIAPHRAGM.—Probably in consequence of the law of averages we have seen a fairly large number of projectiles included in the diaphragm, and pointing sometimes upwards, sometimes downwards.

They seemed to us to present a regular clinical characteristic, viz. · *the very great pain they cause during inspiration.* They even prevent respiration on that account. One of

* As is shown by some rare published observations.

those operated upon by us, a sapper and miner, did not breathe at all with his left side. He showed a strong right scoliosis, and a marked lowering of the left shoulder. Very thin, he was always in pain, and tried to immobilise the left side of his chest. The projectile had been present for a year when we saw him, and he was deeply cachectic. He appeared to be very much better after the operation.

The only route of access is the transpleural way which is very convenient and very easy. By raising one side temporarily as we have shown, one can see very well what one is doing. We have generally put a suture into the diaphragm, although the wound in it has never seemed to us to bleed.

III—Abdomen

§ 67. **Projectiles in the Liver.**—The only indication for the extraction of intrahepatic projectiles which we have noticed is the severe pain referred to the right shoulder when this pain dates back a long time, is permanent, and does not yield to medical treatment.

The projectiles which we have extracted from the liver were not very deeply situated in the gland, with exception of one rifle bullet which we had to look for through about six centimeters of hepatic tissue. In that case we bored our opening slowly with a blunt instrument and we effected the extraction without any considerable hæmorrhage. We were able to discover that the point of the projectile projected from the liver and had penetrated the diaphragm, to which the extreme pain suffered was probably due. We left a hæmostatic tent in the wound for forty-eight hours. The patient recovered without any signs of jaundice or discharge of bile. Nevertheless, if our anatomical diagnosis had been better, we should have operated by the transpleural route, which would have been infinitely simpler.

In connection with this we may refer to our remarks in Chapter XI on the difficulties of the localisation of projectiles of the sub-diaphragmatic region, and especially of those which are located under the right cupola, where the large mass of the liver being of uniform opacity, sometimes places serious obstacles in the way of accurate anatomical localisation.

PLATE VII

FIG. 1.—Radiograph of the thorax seen from the front. One notices, standing out clearly in the shadow of the heart on account of its opacity, the shadow of a round projectile (most probably shrapnel from its shape as well as from the history of the injury) which lies at the level of the right auricle.

FIG. 2.—Radiograph of the thorax of the same patient in the oblique examination. The shadow of the shrapnel is still seen in the cardiac shadow at a level which seems to correspond to that of the right auricle. The projectile is therefore intracardiac and, as the radioscopic examination showed, free in the cavity of the auricle. (This observation was published by one of us with two illustrations in the *Journal de Radiologie* for January 1916.)

PLATE VII

FIG. 1

FIG. 2

One should therefore in all these cases, and especially as soon as the operation appears to be likely to present the slightest difficulties, have recourse to all the proper measures for ascertaining the exact site of the foreign body. The radioscopical examination will be undertaken not only from the front, but also from the side, and it will be completed as may be necessary by one or several negatives. Here also it may be advisable to use stereoscopic radiography, although one generally only obtains a not very satisfactory impression of relief of the hepatic image owing to the uniformity of shadow which we have mentioned before and the absence of contrasts. However, it will be rare that one will not succeed, after a complete examination, in knowing whether the projectile is or is not seated in the liver, or at least *under* the diaphragm. It is only when there are pleural adhesions and the costo-diaphragmatic sinus has disappeared that one is sometimes really embarrassed or led into error, as in our previous case. This anatomical localisation is therefore of great importance in order to settle the route of access upon which frequently depends the facility of the operation, the transpleural way being by far the easier.

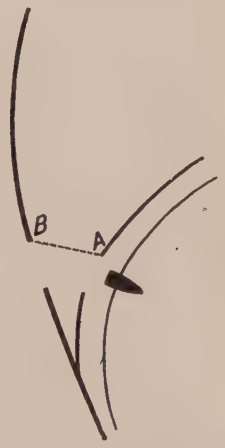


FIG. 214.—The internal lip *A* of the diaphragmatic wound is united to the upper lip *B* of the pleural incision.

In another case we extracted by the transpleural and transdiaphragmatic way a projectile embedded in the posterior border of the liver and round which was an abscess as large as a small nut. After packing the wound to protect the pleura, we united the internal lip of the diaphragmatic wound to the upper lip of the pleural incision, thus placing the track outside and isolating it from the reconstituted pleural cavity (Fig. 214). The pleura did not become infected and the cure was rapid.

In the case of another patient, we removed an aseptic projectile seated between the liver and the diaphragm very easily by that route.

Another projectile at a depth of forty-two millimeters, was very easily extracted from the anterior border of the liver after a laparotomy parallel to the costal margin.

§ 68. **Projectiles in the Abdominal Cavity.**—We have seen relatively few of these. We extracted one, a bullet, between the bladder and the upper edge of the pubis. From the cavity in which it was encysted there was a fistula opening in the middle of the fold of the groin. Its extraction was very easy.

Another, a rifle bullet, was embedded in the mesentery, very near its base. It had been searched for unsuccessfully by an excellent surgeon.

We have removed by laparotomy a bullet localised thirty-four millimeters below the seventh rib. It was seated above the stomach, and had perforated the diaphragm. While the projectile was being removed, air entered the pleural cavity. If our anatomical localisation had been more precise, we should have certainly preferred the transpleural route, because it was not very easy to unite the diaphragmatic orifice on account of its concavity ; the result, however, was excellent.

We have extracted an intrasplenic shell splinter. We had to incise about one centimeter from the cortex. There was no hæmorrhage and we did not suture the spleen.

Finally, we have removed a bullet from a Senegalese sharp-shooter which, clinically, seemed entirely free in the abdominal cavity. It was enveloped and encysted in the extremity of one of the appendices epiploicæ, as large as the little finger, about twelve centim ters long, and it could be displaced from one iliac fossa to the other. The operation was very easy. This extraction would probably have been impossible by the use of the compass (see Chapter XII).

§ 69. **Projectiles in the Internal Iliac Fossa.**—This is a common situation for projectiles, and they are difficult to extract. The frequency is no doubt due to the fact that the iliac bone stops a projectile which has exhausted the greater part of its live force.

They are difficult to extract, because the route of access which we may consider surgically to be the best may be not easily placed in the path of the normal ray.

These projectiles sometimes enter through the buttock,

perforate the iliac bone, and stop in the centre of the fracture in the middle of the splinters. These cases are the most frequent. Sometimes they cross the abdominal wall and stop against the bone intact, in the thickness of the psoas or of the iliacus muscle.

In order to reach them we have always followed the extra-peritoneal way. We have prolonged outside, towards the antero-superior iliac spine and even higher, the recognised incision for ligature of the iliac artery. Raising the peritoneum gradually and holding it up with a wide retractor, we have always been able to reach the projectile. In order to be able to use the normal ray one of the buttocks of the wounded should be raised by a ball cushion filled with oats. The wide retractor should be strongly drawn inwards by an assistant. By this means we can obtain sufficient space and a sufficiently wide route of access.

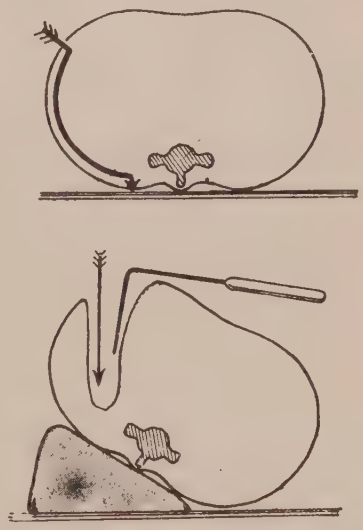


FIG. 215.—These two drawings show how one will always be able to place the patient conveniently in order to follow the normal ray and go down vertically upon the projectile.

The real danger consists in the proximity of the bifurcation of the inferior vena cava. We have had a bitter experience of this.

One of our patients had in the region of the bifurcation a bullet giving rise to great pain. At the moment of extracting it we had a very bad hæmorrhage, which was overcome by packing. On the fifth day when this packing was removed the hæmorrhage recommenced. The wound was again packed. The patient died suddenly on the seventh day from embolism.

In another case a shell splinter was located in the same region. We established contact with it, but it resisted our efforts to extract it. With a curette we levered it up by its rough surface to free it. We managed to displace it,

but a hæmorrhage occurred. We arrested this with a finger, and were able to place two forceps above and below the bleeding point, which partially stopped the bleeding. Our forceps however had not grasped the artery, which continued to beat. A moderate packing however completely arrested the hæmorrhage.

After our experience in the previous case we did not remove the tents and forceps until the twelfth day, and recovery took place.

Finally, one of us collaborated with Labey in a difficult extraction of a splinter situated in the main iliac vein which was removed by laparotomy.

The back and lower part of the internal iliac fossa, corresponding to the anterior surface of the sacro-iliac symphysis, and the posterior part of the upper inlet are therefore very dangerous regions.

As one approaches the antero-superior iliac spine the extractions become on the other hand more and more easy and less dangerous.

IV—Spine. Pelvis

§ 70. **Projectiles in the Spine.**—These are very frequent. Those which are arrested by the spinous processes are superficial and easy to extract. We have not seen any of them ourselves. Those sent to us were principally cases in which the projectiles were arrested by the transverse or articular processes or the heads of the ribs These projectiles often give rise to great pain owing to pressure on nerve roots.

We have nearly always found round these projectiles bony capsules of recent formation, and they had to be removed with the gouge.

We leave alone projectiles included in the bodies of the vertebræ, which appeared to us to give rise to no special trouble, and we thought that the damage done in extracting them would be more harmful than the existing inconvenience.

We might mention that one of us on two occasions was able to extract with Brin a shrapnel bullet embedded in the thickness of the body of the third lumbar. The operation was performed in the nephrectomy position, but

it was possible to follow the projectile with the fluoroscope and to supply the necessary control information.*

When reading the published observations it seems (see Sauve, Surgical Society, July 1916) that the surgeon too often stops in the course of an operation for extracting a projectile in the pelvic region on account of the extent of the damage which must be inflicted, even when the projectile has been localised very accurately as to depth. We have already stated (Chapter XI) that a lateral radiograph which can always be made, gives the necessary topographical information in order to avoid in that region unsuccessful operations which are always so regrettable, and which should not be undertaken except with the most complete information available.

Dorsal and Lumbar Intraspinal Projectiles.—We have removed two of these, both shrapnel bullets

The first one was lower dorsal (incomplete paraplegia, loss of control of sphincters). We removed one lamina only, and then opened the dural sheath which seemed unharmed. Through the medullary tissue we noticed the shrapnel bullet which appeared to us *intramedullary*. We separated carefully the lips of this medullary wound at each side and with catch-forceps we extracted the projectile. At the moment when it emerged from the lips of the wound the anæsthetised patient made a violent movement with both legs.

At present he walks with the aid of sticks, but the incontinence of urine persists.

The second case was a shrapnel bullet situated in the second lumbar. The wounded patient showed the symptoms of injury to the cauda equina. Laminectomy was performed and incision of the dural sheath made. The projectile was in the middle of the fibres of the cauda equina and was carefully extracted without injuring any of the fibres. The patient has been discharged, and we have lost sight of him.

Projectiles in the Sacrum.—We have removed eight of these, embedded in the bony tissue at various depths. One was entirely in the lateral mass. Most of them were retained in bony capsules formed partly by the sacrum and partly by new formation of bone. We have always

* See Brm, *Bull. soc. chirurgie*, February 1st, 1916.

approached them from the back with the gouge and mallet. In one case, the projectile, situated in the first sacral, was in the middle of the cauda equina, inside the dural sheath. This patient is now an aviator and has already undergone several tests as a pilot. Another of these patients stayed several months in a Paris hospital and was considered after a negative radiological examination as a malingerer. His projectile was however easily to be seen even on the screen.

Deep Projectiles in the Perinæum: Ischio-rectal Fossæ.—It is extremely difficult to obtain a normal ray with the patient in the position most convenient for the surgeon for operation.

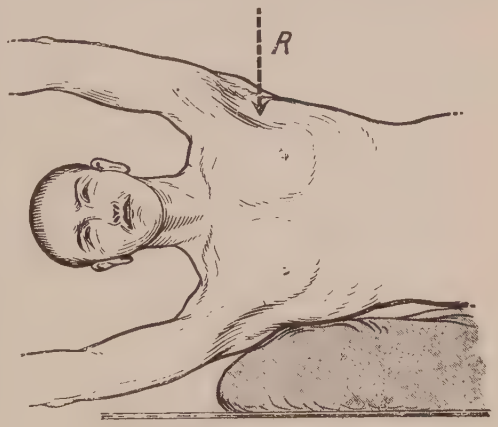
The patient should be placed in the lithotomy position for extractions of projectiles in this region, and this position in its extreme form is generally satisfactory. Quite recently we met with this difficulty for the first time, which can be avoided by moving the tube or by using a double anticathode tube. We do not think that compasses can be used any more conveniently in this situation.

V—Limbs

§ 71. **Projectiles in the Axilla and Sub-scapular Region.**—These projectiles are frequent and rather difficult to extract. They are frequent because the scapula acts as an obstacle to the passage of projectiles.

They are rather difficult because an attitude which is not generally used must be chosen to cause the normal ray to follow the surgical route of access, which can only be via the axilla. The difficulty consists solely in keeping the anæsthetised patient in the position required by the radiologist. This consists in maintaining the arms raised vertically (in the anatomical sense), so as to leave the axilla clear, the patient lying on one side which rests on an oat ball cushion. Moreover, the shoulder of the side of the operation should be a little behind the sound shoulder, in order to avoid superposing the images of the scapulæ (Fig. 216). Even then it is not rare that the surgical route of access is somewhat oblique in relation to the normal ray, which necessitates, in the course of the operation, a few displacements of the body of the patient, to re-

establish the coincidence of the route followed by the surgeon and of the normal ray or a movement of the tube to ascertain the relative positions of the projectile and of the surgical instrument during the operation.



PROJECTILES IN THE ARM, THE ELBOW, THE FOREARM, THE WRIST, AND THE HAND. — One knows how easily these projectiles are extracted after a preceding radiological examination with the aid of the control of the screen. Nothing special need be said of them.

PROJECTILES IN THE HIP, BUTTOCK, THIGH, KNEE, AND LEG.— Like the projectiles of the shoulder projectiles of the hip are sometimes very difficult to extract, the cause being too often an incomplete radiological localisation, giving simply a depth, but without fixing whether the projectile is above or below the neck of the femur or in the bone. The result is that the choice of the way of access is somewhat haphazard.

FIG. 216. — Position chosen to approach a projectile in the axilla most easily.

This difficulty disappears when we have accurate information.

Small projectiles hidden in the buttocks and projectiles in the muscular masses of the thigh can only be successfully extracted with the aid of the intermittent control of the screen.

PROJECTILES OF THE FOOT.—No matter what the situation may be of these projectiles which so often give rise to

pain on walking, the route of access should never be through the sole, in order to avoid the presence of a painful scar.

The projectile will therefore be approached either through the dorsum of the foot or through the lateral side, according to the situation, but never through the sole. In difficult cases an examination in two different directions will always bring the instrument in contact wth the fragment to be extracted (Figs. 217 and 218).

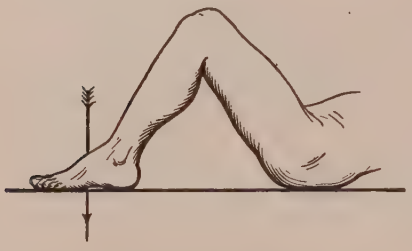


FIG. 217.—Position chosen for projectiles of the foot. Dorsal view.

PROJECTILES IN THE NERVES.—We have often removed projectiles, even of very small size, adjacent to the nerves in limbs causing great pain from their proximity to them. Only twice, however, have we found metal bodies included in the nerves.

In one case a thin sharp-pointed metal fragment ran through the radial nerve. In another case a fragment was

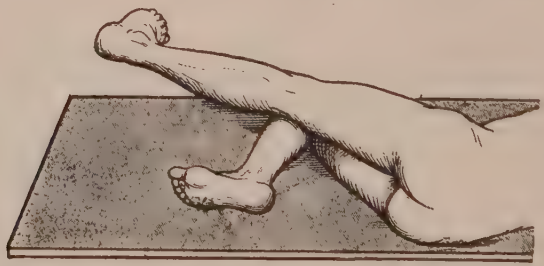


FIG. 218.—Position chosen for projectiles of the foot. Lateral view.

included in the interior of a fusiform neuroma of the sciatic nerve.

PROJECTILES OF THE VESSELS.—We have removed metal fragments which appeared retained in the walls of the brachial and of the popliteal vessels.

Can a projectile penetrate into the lumen of a vessel, especially of a vein, and block the orifice? This seems

possible to us. The two cases of hæmorrhage of the iliac vessels reported above may be explained thus. We remember an observation by *Robineau* in which the traction on a shell splinter opened the popliteal vein. However, it is possible that in the actual extraction the rough shell splinter may tear the thinned vascular wall to which it adheres. We do not know of any real fact to indicate that a projectile has spontaneously and secondarily eroded and perforated a thick vessel. This is however a possibility which the well-known accidents of arterial wear in contact with drainage tubes for instance permit us to consider probable. It might lead us to undertake certain extractions systematically and in regions particularly difficult. It seems that a more extensive experience should be awaited before committing oneself definitely on this point.

To sum up, the simple problem to be solved for each region is always the same. It comes to choosing a route of access which can be rendered rectilinear, and to place this rectilinear route of access in a manner to cause it to coincide with the normal ray.

We have just shown that, with exception perhaps as regards the perinæum and the ischio-rectal fossæ, this is always possible. Even where it is not possible the examination in two different positions and the observation obtained by mobilising the tube will always give the radiologist sufficient information to enable him to guide the surgeon's instrument until contact with the projectile is established.

§ 72. VI. **Complications associated with Projectiles.**—Abscesses.—The projectiles very often form abscesses round themselves, even after apparent healing. Owing to the special conditions under which our services under Descartes at Tours have worked, we have never observed these to occur. It is probable that all the late abscesses which occurred in the limbs were opened at the front without being referred to the consulting surgeon, and that the doctors attending have then simply extracted the projectile bathed in the pus. We have noticed instances of this. We, who have had to deal with the deep projectiles which appeared difficult to extract, have only noticed once an abscess of the size of a nut round a projectile near the

PLATE VIII

Fig. 1.—Radiograph of the thorax right oblique front view. One will see, in the middle clear space, the shadow of a projectile absolutely distinct from the shadow of the heart. This projectile is therefore certainly not intracardiac, as had been affirmed, although it projects inside the shadow of the heart in all the other positions, which explains the error of diagnosis made by inexperienced radiologists.

Fig. 2.—Radiograph of the left shoulder seen from the back. The shadow of a deformed shrapnel is projected over the free extremity of the coracoid. Another small fragment of projectile has been detached and its shadow is seen in the soft parts internal to the coracoid (compare Fig. 97).

Fig. 3.—Radiograph of the right hand seen from its palmar aspect. Innumerable metal particles and fragments of very small size (grenade injury).

Fig. 4.—Radiograph of the right hand seen from the palmar aspect. Trail of metal particles, fragments of very small volume. Notice the intense decalcification, particularly marked at the level of the epiphyses, of all the bones of the hand.

PLATE VIII

FIG. 1

FIG. 2

FIG. 3

FIG. 4

diaphragm penetrating the convexity of the liver (see above).

What we have seen frequently, in the viscera as well as in the muscular masses, is a small encysted cavity containing some granulations with some thick liquid, yellowish, or more often coloured by the metal oxides of a black or mahogany-red colour. These cystic sacs contain a projectile almost floating in their centre, which can be removed with extreme ease, but when this sac does not exist the shell fragments on the contrary frequently adhere very firmly to the tissues in which they have been retained a long time.

The contents of the sacs never seemed to us to be very virulent. In these cases also the result of various researches made must be awaited, some of which are already published, and especially the reports on the septic troubles which may result from the prolonged retention of projectiles.

SPLINTERS.—In the course of the extraction of a projectile it has happened to us several times that we have removed bony splinters which we found on the course of the route of access. During the extraction of a projectile in the lung of an officer whose operation had been postponed several times we removed first a bony fragment probably of a rib, and found the metal body two centimeters deeper.

The intermittent control of the screen enabled us to be certain that the projectile was still there after the splinter had been extracted and that the operation was not finished. Probably we should have hesitated with any other method and we should have asked ourselves anxiously whether the bony fragment which we had just removed was or was not the foreign body the presence of which was revealed by the radiograph.

We have never found any fragments of clothing or other foreign bodies in contact with any projectile which had been retained and remained aseptic.

Operative Results of Aseptic Extractions.—Our organisation at the Descartes school is surgically as perfect as that of the surgical service of one of us in Paris. Our assistants are the students studying surgery. Under these circumstances therefore, considering the results which we always obtain in aseptic surgery, we have a right to say that if

certain septic incidents happen to complicate with a certain frequency some special operations they are due to something else than contamination due to the operative technique.

Although when projectiles are extracted from the soft parts healing takes place as a general rule and, in the very great majority of cases, by first intention, we have noticed that oozing of thick serum for eight days or so generally occurs when these cystic sacs have been present, although we generally curetted the cavity.

On the other hand we have nearly always observed some osteomyelitis and suppuration lasting from fifteen days to six weeks whenever the projectile was extracted from the site of a compound fracture with splinters. In these cases there are nearly always granulations round the projectile. It has also seemed to us that the centres containing shell splinters showed themselves more virulent than those in which smooth projectiles, bullets or shrapnel bullets, were included. In any case we have never seen these discharges or these osteomyelitic foci give any cause for anxiety.

Anæsthesia.—It is hardly necessary to point out that in the extractions of projectiles with the aid of the intermittent control of the screen the anæsthesia must frequently be administered with the patient lying on his face. The fears of some surgeons who have had no experience of this procedure are absolutely without foundation. The only possible trouble concerns the anæsthetist only and consists in the difficulty which he may encounter in following the patient well and freeing his head sufficiently to apply the Ombrédanne apparatus which we use exclusively. By placing a cushion under the thorax or the shoulders and inclining the head this little difficulty will be very easily overcome. An ingenious inventor of the 9th region, whose improvised radiological table we have mentioned (Chapter IV, Fig. 72), has added to it a device which permits us to raise the plane of the table higher and to keep a free space for the head to render the anæsthesia more convenient.

The same manœuvre can be carried out with our radiological table, but it is not indispensable.

§ 73. **Search for Foreign Bodies other than Projectiles.**—As this work is essentially devoted to the search for *pro-*

jectiles we have so far hardly mentioned other foreign bodies.

It is hardly necessary to point out that all that we have explained applies without any modification to *the other metallic foreign bodies* which the surgeon may have to deal with in the course of his practice and especially to the metal foreign bodies so frequently swallowed or inspired by children. We trust that recourse will henceforth be more frequently made to their radioscopical localisation and extraction with the aid of the intermittent control. One may refer with much advantage as regards this point to the important works by Henrard who has recommended and successfully practised for a long time the search for œsophageal foreign bodies with the screen.* It is a valuable adjuvant to bronchoscopy for those who know the use of it in exploration and extraction.

But apart from the metal foreign bodies there are numerous foreign bodies introduced in the organism or formed in the thickness of the tissues for which the principles laid down in this work can be utilised with advantage.

For all those which their relatively small opacity (renal calculus, gall stones, enteroliths, and small splinters, etc.) renders radioscopy less useful, radiographic localisation will give greater and more accurate help. We may employ with advantage compasses, especially the Hirtz compass, for this purpose. In civil practice when time is less precious and expense is less important, the multiple uses to which this admirable instrument lends itself admirably will be found of great value.

We shall not deal further with this subject which is capable of interesting developments, as this would carry us outside the scope of this work. We shall content ourselves with having pointed it out to the attention of the reader.

* One will also consult with advantage the recent work by Chevalier Jackson, *Peroral Bronchoscopy* (Saint-Louis, 1916).

CHAPTER XV

THE SEARCH FOR PROJECTILES BY NON-RADIOLOGICAL METHODS

§ 74 The great facilities, the perfect security which the radiological methods afford us *in all cases* can induce us to think that it is absolutely useless to consider any other method. However even now one may desire to use either for the detection or especially for the extraction of the projectiles *after the radiological localisation* the aid of accessory apparatus in the cases—which, we hope, become more and more rare—in which the operator cannot avail himself of the intermittent control of the screen.

We are going to describe briefly the principal methods which one will do well to retain and which have already stood a test. We shall not deal, of course, with the exploration with the speculum, the only serious process of examination at the disposal of the doctors in former times, nor with chemical reagents. We shall neither try to trace the history—which is very interesting—of this matter, and we refer the reader to the articles in the medical dictionaries. We shall limit ourselves to the study of the modern methods which are all based, like the X-rays, on the direct or indirect use of electricity.*

Projectiles are essentially metal fragments consisting in most cases of steel, iron, or cast-iron. They are therefore always *conducting* bodies and most often *magnetic* substances. These are the two chief characteristics which are going to serve as a basis for all methods of search which we shall describe in this chapter.

* One may consult with advantage in this connection the excellent *Manual of Electro-therapeutics* by Albert-Weil (new edition, Paris, Alcan, 1916), an article by the same author in the *Paris Médical* and a very instructive article by Lebon in the *Science et la Vie*. We have borrowed largely from these authors.

I—Search for Magnetic Projectiles

Efforts have been made for a long time to make use of the fact that large numbers of projectiles are magnetic in order to find them more easily. Advantage has been taken for some extractions of the properties of *natural magnets*, but their weak force limits their application to a great extent.

With the discovery of *electro-magnets* the power has grown to such proportions that one has been able, as is well known, to apply in a continuous manner (and especially in the domain of ophthalmology) the magnetic attraction for the search and extraction of metal fragments.

Finally, since the war, at the same time as this application of the magnets developed, M. Bergonié has given a fresh impulse to the employment of alternating electro-magnets which excite the vibration of the magnetical bodies and consequently facilitate their detection in the tissues.

We shall distinguish: (1) magnets destined for the attraction, the mobilisation, and the extraction itself of the projectiles—these are the electro-magnets fed by continuous current; and (2) magnets destined exclusively for revealing the presence of the projectile by causing it to vibrate—these are the electro-magnets fed by alternate current or electro-vibrators.

(1) *Continuous Electro-Magnets.**—Theoretically one could, by supposing an electro-magnet sufficiently powerful, effect directly, through attraction through the tissues of the body, the extraction of the magnetic projectiles, as is practised for the globe of the eye. M. Bergonié and M. Rollet have published papers on these lines and related cases in which the magnet had "mobilised" and brought to the surface projectiles which were deeply retained, or revealed by the raising of the skin the presence of the foreign body and its approximate site. Without speaking of the practical difficulties of the application originating in the necessary power for the electro-magnet, one will easily understand, without it being necessary to emphasise the point, all the dangers which may result from such a

* See Thompson, *The Electro-Magnet*, 1 vol. 18mo (Paris; Des forges).

blind manner of proceeding. It is therefore not surprising that one has not adopted this method more extensively which seems mainly applicable to ophthalmological applications.

The utilisation of the continuous electro-magnets is interesting in *the extraction of projectiles by direct contact in the wounds.* Especially at the front in the case of recent wounds which are still open and into which can be sunk the metal sterile point of an electro-magnet this practice will render according to our belief frequent services, although the necessary provision of a *powerful electric circuit* restricts its application.

Fig. 219.—Dr. Lyonnais' electro-magnet, with one of its spare points.

Finally, in the course of surgical extractions of long-retained projectiles we think it will always be useful to have at one's disposal a continuous electro-magnet. We often employ advantageously the type shown herewith (Fig. 219), constructed for us by Dr. Lyonnais (of Doué-la-Fontaine) not for taking out a projectile which is still included in the tissues, but simply for "collecting" with a minimum of damage the German bullet or the shell splinter deeply situated, as the removal with the forceps would cause greater injuries or involve difficult manœuvres in the mediastinum, the lung, the deep parts of the buttock, etc. . . . and, *especially, in the brain.** This is a *very valuable adjuvant* of our outfit (but not indispensable). Its utility is obvious in all important and well-organised services. But let us not forget that unless *a really exceptional power* is provided one cannot expect to take out the projectiles through *the slightest layer of interposed tissue.* If it is only as thick as a sheet of cigarette paper it will suffice

* See the preceding chapter.

to prevent the attraction. *The projectile must be able to enter into direct contact with the magnet.* Even if it is easy to obtain a *carrying force* sufficiently high per *square centimeter*, the contact between the point of the magnet and the shell splinter or even the ball is practically limited to one point. Moreover, when an electro-magnet can present a considerable carrying force it only attracts to a relatively small degree a metal fragment which is not immediately in contact with its pole, this being due to the fact that the interference of the interposed substance is considerable and also that the flow diminishes very quickly if one moves away from the poles. The attraction is, approximately, inversely proportional to the *cube* of the distance.

(2) *Alternating or Vibrating Electro-Magnets.**—Taking up on the recommendation of M. Anderson the conclusions of the fine research work by Elihu Thompson on the electro-magnets traversed by alternate currents and the vibrations which they determine in magnetic bodies (and even in certain metals slightly or non-magnetic), M. Bergonié has devised an alternating electro-magnet which is constructed by the firm of Gallot. This is, in short, an inductor of an induction-coil, the apparatus being known under the name of *electro-vibrator*. The magnetic projectiles placed in its field present, in fact, an intense vibration which can be felt and which thus make their presence known.

In order to use it alternating current is of course necessary. If there is only continuous current a rotary converter or, if necessary, turbine interrupter should be employed. The vibrator being essentially very heavy it should as far as possible be suspended from a bracket and it will then be worked easily by means of a counter-weight. The above drawing (Fig. 220) shows the Bergonié apparatus.

The apparatus is applied perpendicularly to the surface to be explored, the fingers being applied to same flatly until the vibration is felt. Then one localises exactly by means of one finger only the point of maximum vibration (Fig. 221). This search is renewed before commencing the operation, then, during its progress, with the finger inserted in the wound. Care must be taken beforehand to protect the

* See the *Archives d'Electricité Médicale* by Bergonié since April 1915. Most of the numbers contain articles devoted to the electro-vibrator.

wound against any possible infection through contact by enveloping the electro-vibrator in a sterile towel.

Moreover the apparatus after a few seconds becomes very hot on account of the intensity of the current which runs through it and sterilises it, but which will not fail to put it out of action if the current is not interrupted every thirty seconds. When the incision is made at the localised point the surgeon is guided by the electro-vibrator into the depth of the wound towards the projectile, by finding with the finger, without pressure, the direction in which the vibration is at its maximum. The operation is then directed towards that point.

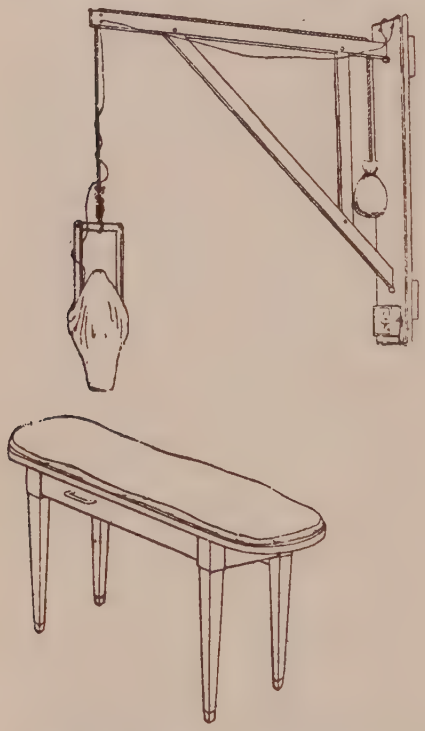


FIG. 220.—The electro-vibrator of Bergonié with counter-weight mounting (bracket) permitting its convenient use above the examination or operation table.

However, all the ordinary instruments used in the operation vibrate, this being singularly troublesome. M. Bergonié has therefore had constructed by M. Collin instruments of a non-vibrating alloy. This however necessitates a rather inconvenient complication of surgical instruments.

The vibrator is a remarkable and excellent instrument which will often enable one to reveal the presence of magnetic projectiles and will render their extraction easy in many cases. However, at least one-quarter of the projectiles searched for are not magnetic and do not vibrate, or at least do not vibrate with certainty. A negative

exploration with the electro-vibrator *will therefore by no means prove* that there is no projectile present and that *a radiological examination can be dispensed with.* Moreover, it very often happens that magnetic projectiles are either too deeply situated (more than 10 centimeters) or are too firmly included in the bone to vibrate. Besides, a great difficulty lies frequently in the determination of the *maximum point of vibration.* Finally, even when the projectile vibrates and there is a point of vibration, the surgeon is still without any information as regards the real depth and the anatomical site of the projectile, and if he operates without further examination only under the conduct of the vibrator, he will always find himself in the situation of the operator who would rely on the control of the screen in order to conduct him to a projectile not localised, this without as much as a preceding examination at two different angles, and who would be certain to make mistakes. We have more than once extracted magnetic projectiles relatively rather easily which excellent surgeons could not find by means of the electro-vibrator.

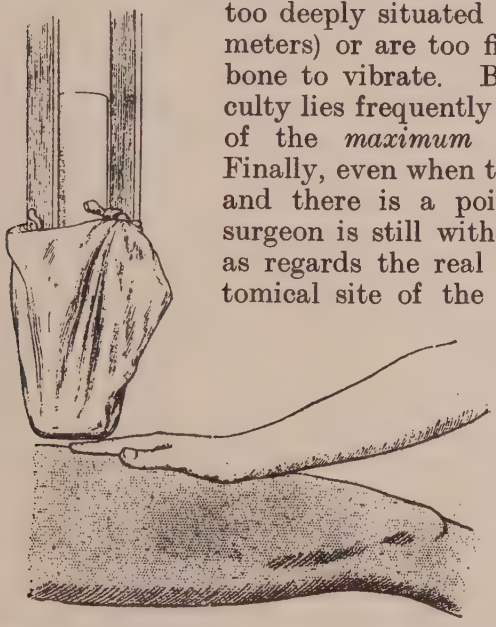


FIG. 221.—Searching for a projectile by means of the electro-vibrator.

Therefore *a complete radiological examination should be undertaken in all the cases with localisation* of the projectiles which one intends to extract with the vibrator. This involves consequently a complication of the outfit, without being of universal application. As M. Rechou very rightly observes, if one possesses a general means one must neglect the particular means.

One must not forget moreover that the vibrator, to be of real assistance, should work under well-determined condi-

tions by using a *considerable energy* which must not be less, according to M. Bergonié himself, than 60 ampères at 110 volts, which nearly always requires the provision of special wiring which is very expensive.

An effort has since been made to produce an instrument rendering the same service with a smaller consumption of energy and of less weight.

Thus MM. Picquet and Egal have constructed a vibrator which presents a much more satisfactory yield although its size and weight are very much reduced. Their apparatus only weighs 4 kilos. The core of the coil, consisting of tempered mild-iron plate blades, insulated by paper, only measures 10 centimeters long by 5 round. It is surrounded by 200 turns of copper wire of 18/10. The coil is mounted in the manner of an axe, to one of the ends of a wooden handle of 70 centimeters. At the other end is a switch. An assistant holds this handle with both hands and holds the vibrator enveloped in a cover of sterilised cloth above the patient in all the positions required by the surgeon. A strap placed round the neck of the assistant facilitates his task in supporting the handle of the apparatus, the most remarkable quality of which is to work efficiently with 15 ampères at 110 volts.*

§ 75. **The Electrical Detection of Projectiles.**—A. *The Induction Balance and its Derivatives.* The Bergonié vibrator is not the only apparatus which is capable of demonstrating the presence of metal projectiles situated in the tissues before incision or the exploration of the wound. A series of very ingenious instruments based on the fact that most metals are infinitely better conductors for the magnetic lines of force than the greater number of other bodies, derived more or less directly from the Hughes balance, can supply us with the same information.†

Hughes has termed *induction balance* an apparatus in which four solenoids (or windings of conducting wire) *A*, *B*, *C*, *D*, are connected two to two (Fig. 222). In the group *A*, *B*, called *inductor* a current circulates which is

* For all details concerning this apparatus refer to the article in *The Radiological Journal* of October 1916.

† We only mention in passing the deviation of the magnetised needle of the compass near the projectiles mentioned by M. Baudouin, but which is only very rarely of practical importance.

supplied by a pile and broken at rapid intervals by an interrupter. The second group, called *induced*, is closed by a telephone. However, one has wound on a similar cylinder or on a similar coil an inductor solenoid and an induced solenoid, *A* is thus connected with *C*, *B* connected with *D*, and the groups *AC*, *BD* constitute each *one of the supports of the balance*.

Now, the inductor and induced windings are in opposite directions. Therefore if the two couples of solenoids are identical (same number of turns and same wire) the two currents which are created in the induced coils are necessarily equal, but opposite, and in consequence they completely neutralise one another. The telephone is then not sensitive and gives no sound. But if on the contrary one makes arrangements that one of the induced currents should exceed the other in intensity, even to a very small degree, then the telephone is audible. What must one do in order to obtain this result? Simply break down the condition of magnetic equilibrium of the area surrounding the two induced coils, by bringing any metal body near to the turns of one of them so that it may be traversed by the lines of force of its magnetic field. Thus it develops in the metal body induction currents which create a magnetic field, which, by reacting on that of the coil, modifies the value of the current which is induced in the latter. The two induced currents being no longer equal do not destroy themselves completely, and the difference passes through the telephone causing a sound to be heard. Pro-

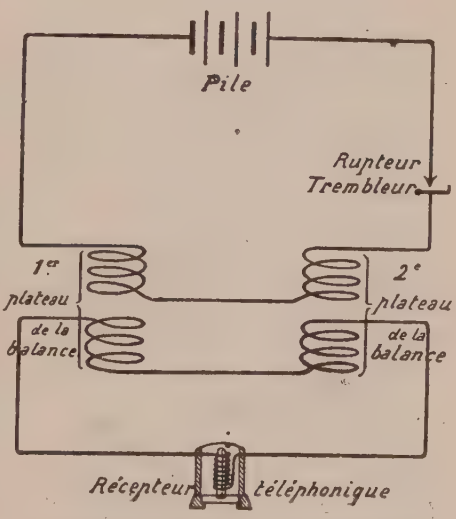


FIG. 222.—Drawing of the Hughes induction balance.

fessor Lippmann reported in November 1914 that the electro-magnetic balance could be advantageously used for discovering projectiles in the tissues.

Kaufmann, who seems to have been the first to think of this use, has simply replaced the clockwork mechanism, which interrupts the current in the circuit of the inductor group of the Hughes apparatus, by a microphone which is connected with a watch. The ticking of the latter produces the alternate make and break of the primary circuit (inductor group) necessary for inducing the currents in the secondary circuit (induced group). The coils being made very small one can easily pass one of the cylinders over the body of the patient. The vibrations of the telephone increase as one approaches the region where the metal body is situated, attaining the highest intensity when one is immediately above, then diminishing until it ceases entirely, when one moves away from it.

M. Chilowsky has had constructed by the firm of Gallot an induction apparatus which only has two coils placed symmetrically in planes perpendicular one to the other (Fig. 223). It follows that the induced coil is not traversed by the lines of magnetic force of the inducing coil. No current can therefore normally make the telephone which is inserted in its circuit sensitive. But if a metal body is placed in the field of the inducing coil and outside the plane of the second soil, induction currents will be developed in that body the magnetic field of which will influence the induced coil and creating a current which will cause the telephone to sound. Hence we conclude that the plane of the induced coil constitutes a plane of extinction of the sound and that of the inducing coil a plane of maximum audibility permitting us to determine the position of the metal, if, as in the case under review, we move the apparatus above a region which a metal fragment may be retained. In practice, as it is difficult to construct the apparatus in such a manner that the planes of the two coils are strictly perpendicular, we introduce in the interior of the induced coil, in series with same and in the same plane, a third coil, capable of turning round a horizontal axis which permits us to regulate the apparatus to zero, that is to say to obtain complete and perfect neutralisation of the inducing and induced coils.

Chilowsky later modified his apparatus by forming it of three coils disposed in three planes perpendicular one to the other (Fig. 223); in order to make it more compact, the induced coil of the first apparatus is replaced by two smaller coils in the form of a cross. Thus he has produced an electrical sound of small diameter which can be introduced into wounds or incisions.

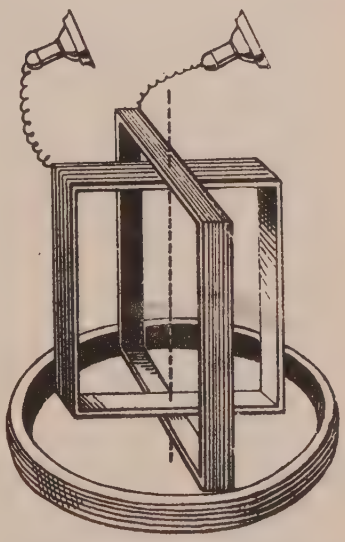


Fig. 223.—Chilowsky's modified apparatus showing the three coils perpendicular between themselves and the telephonic receivers.

Apparatus of this type is only efficient when the bodies to be found are not deeper than one to two centimeters. Their use is therefore very limited.

The "searcher-localiser" invented by M. François has a more important range of action. It comprises essentially:

(1) A first group, called *fixed group*, formed of two identical coils placed in the prolongation of one another on a stand bearing also the devices for regulating the sensibility and the various connecting terminals. One is fixed, the other one mobile. The mobile coil represents one of the two essentials for regulation. The other one consists of a small metal ball surmounting a rod fixed on the stand by a joint link which allows the ball to be approximated or withdrawn from the coils.

(2) A second group of coils wound one at the side of the other which constitutes the exploring element, the properly so-called searcher-localiser, the weight of which is very small, about 350 grammes.

(3) A telephone receiver mounted on a head-clamp with a metal spring.

(4) A small box containing a non-polarisable three-element battery and a trembler interrupter intended to

produce a rapid succession of makes and breaks of the primary circuit (fixed group).

The outfit can be used in a very simple way.* After having placed the stand carrying the fixed group on a non-metallic support, and having removed the searcher from the field of regulating coils and the box containing the battery and the interrupter, so that the noise of the trembler does not interfere with the sound heard in the telephone, the operator puts on the headpiece. Should he hear a noise it shows that the balance is not in equilibrium; he therefore proceeds to regulate it which after a little experience can be done in a few seconds.

In order to localise the projectile in the tissues the surgeon passes the searcher lightly over the region supposed to contain it, being careful to maintain it as far as possible perpendicular to the surface of the body. As soon as the instrument approaches the metal object sufficiently near to develop induction currents the telephone starts ringing. The sound heard in the receivers is the more intense as the axial line of the searcher approaches the projectile; by passing the instrument in every direction, we shall find the point where the intensity of the sound is at its maximum.

According to their size splinters of steel, iron or cast iron are discovered by the searcher at more or less great depths. Other metals such as copper (French bullet), lead, bronze, gold, silver, aluminium, etc., influence the apparatus at depths which are also in relation to the size. It is however evident that the more magnetic a metal is, the larger the distance at which it reacts on the exploring coil.

A close determination of the depth may be obtained with the searcher. We effect it by comparing the sound produced by the projectile in the telephone with the sound produced by a small piece of the same metal. This piece is brought more or less near to the searcher, and it is made to slide on a small graduated rule placed in the axis of the apparatus. A good and exercised ear determines as easily the instant when the intensity of the two sounds are equal as a musician is able to pitch two strings of the same tonality; all that is necessary to do afterwards is to read

* See the communication of M. François to the Academy of Medicine and the articles already mentioned, by Messrs. Lebon and Albert-Weil.

on the rule the distance which separates the metal object from the searcher in order to know the approximate depth of the projectile in the tissues.

We may close the series of appliances based on the Hughes induction balance by mentioning the finger-stall

FIG. 224.—The audioscopic finger-stall by M. A. de la Baume-Pluvinel (Gallot & Co.). We see on the diagram the four principal parts of which the appliance consists. (1) The source of the vibrating current constituted by a coil (*A*) with a rapid trembler (*L*) (fed by two dry batteries) contained in a box which also is used for transporting all other accessories. (2) The compensator (*B*) which must be placed on a wooden support not containing any metal part and which is regulated by means of a fly-wheel (*V*). (3) The telephone receivers (T_1, T_2). (4) The finger-stall (*D*) (which is placed on a finger which is little used normally, say the middle finger of the left hand) and which contains the exploring coil in the shape of a pastille.

of M. A. de la Baume-Pluvinel (Gallot & Co., manufacturers) the object of which is to provide the extremity of the surgeon's finger with a small appliance which would enable him, by exploring the interior of the wound, to recognise the direction in which it is best to open the tissues in order to reach the foreign body in the most direct possible way. His apparatus gives the desired effect under excellent conditions and seems to us to be by far the most original, the most attractive, as well as the most useful of the instruments of this series.

It is in reality the exploring coil of the Hughes balance ; only the surgeon places it on one of his fingers (instead of fixing it on a sleeve as the François sound) preferably on the top of the middle finger of the left hand and maintains it in place by means of a finger-stall of sterilised rubber. He thereupon introduces the finger into the wound or the incision and turns it round in order to explore the walls. This appliance has the advantage of being easily handled owing to the mobility of the finger. However, its shortness does not give it great sensibility. The metal body must not be further than one to two cm. from the extremity of the finger in order that the operator should be usefully guided, but in this case the distance is quite sufficient as the surgeon is generally very near the projectile which he does not feel with the finger.*

§ 76. B. **Electric Explorers and Detectors.**—Although the metals mostly used in the manufacture of projectiles are magnetic it is not the case with all of them ; they are however all conductors. The processes of detecting metal projectiles based on the latter property seem to contra-indicate their general use. They have the great inconvenience of necessitating actual contact, that is to say they can only be used after incision or during the exploration of a wound.

We are going to review them rapidly by quoting textually, as in the foregoing paragraph, from the article published by Dr. H. Lebon in *Science et la Vie*.

Electric Explorer-Extractor by Trouvé.—This instrument is one of the first invented of those which take advantage

* A variation of this appliance intended for exploration before the intervention and having a greater sensibility has just been devised by the same constructors for M. de Gontant-Biron

of the conductive property of metals constituting the projectiles to close an electric circuit having appeared first in 1867. For a certain period it formed part of regulation military and naval medical equipment. The apparatus consists essentially (Fig. 225) of a stylet formed of two small rods of steel, insulated from one another at the lower end and attached at the other end to a small electro-magnet contained in a case in the form of a watch called the revealer fixed to the top of the stylet. This is connected at the other end to the extremities of a battery, and will be traversed by the current whenever the points of the stylet both touch a metallic body thus closing the circuit. It will thus attract the vibrating plate. If we quickly raise and lower the stylet alternately there will be produced a series of makes and breaks of the circuit and the vibrating plate of the electro-magnet revealer will be heard. A body of metal only will be conduct sufficiently to close the circuit as the contact with a splinter of a bone or with any fragment of tissue will not cause any error. But the contact with the projectile is necessary. The instrument may however also be joined to forceps, the insulated branches of which take the place of the rods of the stylet. The metal body when found can thus be easily extracted.

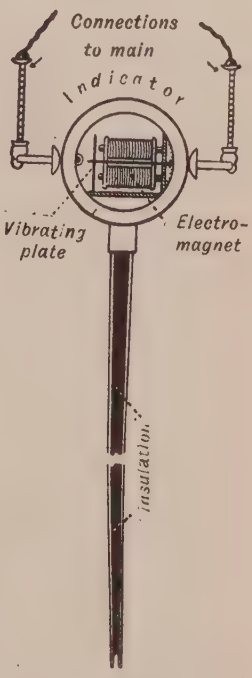


FIG. 225.—The Trouvé electric explorer.

Guilloz of Nancy wished to render the Trouvé apparatus more practical and to that effect he modified it very successfully. His electric trocar is an ordinary trocar the central needle of which, insulated except at its bare extremity, moves inside another metal hollow needle. The two needles are inserted in the circuit of a battery and of a galvanometer or of a bell. The point of the central needle always projects a little beyond the extremity of the hollow needle, owing to an antagonistic spring placed in the handle

of the apparatus ; if the surgeon meets a hard body in the wound the surgeon must press the handle of the trocar so as to overcome the resistance of the spring which prevents the retreat of the central needle ; the two needles come then into contact with the hard body, and if the latter is of metal it establishes a contact between the two points and then the galvanometer or the bell will immediately reveal its presence. Guillot has also designed, on the same principle, an electric needle-carrier explorer which enables one to carry out analgesic injections. He uses instead of the hollow needle of the trocar described above a needle by Pravaz joined to a syringe and pierced by holes lengthwise in such a way that the liquid is instilled into the tissues.

Both the Guilloz apparatus as well as the Trouvé apparatus must be provided with a double contact in order to reveal the presence of a metallic foreign body. The telephonic line by Graham Bell, described about fifteen years ago, requires only one contact. This instrument consists of an ordinary telephone receiver, provided with two conducting wires ; one of these is joined to a silver spoon or even to a simple platinum spiral and the other is fixed to a copper or steel rod of small diameter. The patient places a part of the spoon or of the spiral into his mouth and the surgeon explores the wound with a metal rod, holding at the same time near his ears a telephone receiver which may be replaced with advantage by Hedley's ultra-sensitive double listening headpiece, which enables the surgeon to have the free use of both his hands. As soon as the probe comes into contact with the projectile a sharp characteristic noise is heard in the telephone. Dr. H. Henrard, the very eminent radiologist of Brussels, has replaced the spoon by a lead plate covered with compressed gauze soaked with a saline solution and he fixes this by means of a bandage to the surface of the patient's skin. A conductor joins this plate of lead to a telephone receiver mounted on a headpiece ; this receiver is joined to a probe, bistoury, needle of a hypodermic syringe or forceps which can be introduced into the wound. In either case (spoon or lead plate) the voltaic couple which produces the current required for making the telephone sensitive is obtained without a proper battery : in the first case the saliva of the patient serves as an electrolyte, as the silver of the spoon and the copper

of the probe play the part of anode and of cathode; in the second case the saline solution on the one hand, the lead of the plate and the metal of the exploring instrument on the other hand, fulfil the same object.

To the Henrard telephone apparatus which is accessible to every physician even in a country place, we may add a battery and an electrolytic detector similar to that of Colonel Ferrié, used in wireless telegraphy, in order to improve the audibility of the sound in the receiver. This has been accomplished by Messrs. Mauclaire and Garin. A buzzing or fizzing noise is then produced in the receivers during the whole length of the contact of the surgical instrument with the foreign metal body. In order to find the contact in an irregular course, Messrs. Mauclaire and Garin propose the use of a probe in the interior of which pass two conductor lines, one being joined to the positive pole of the battery and the other to the negative pole through the detector, ending at the metallic projections placed at the extremity of the sounding line. It is however recognised that with this apparatus as well as with any other contact probe we may obtain negative results, owing to the deposit of blood or of fatty or serous liquid which forms an insulating cover round the projectile.

Finally the Cambridge Scientific Instruments Co. has recently constructed on the same principles an instrument in which the telephone is replaced by a strong and transportable though sensitive galvanometer. The errors produced by the buzzing in the telephone receiver are thus avoided. Two conductor wires lead to the galvanometer and are connected one to the exploring probe proper and the other to a " contact " of the same metal as the probe and which is fixed in a corner of the wound. No difference of potential would be established between the probe and the contact, as both are constituted of the same metal. But as soon as the explorer has come into contact with another metal in the wound, the voltaic element is formed and the galvanometer deviates. Its sensitiveness is such that a metal fragment of only 1 millimeter in diameter causes the needle to deviate by 10 to 20 degrees (about 3 centimeters on the scale).

To sum up, we see that if the electro-vibrator, the induction balance and the telephone probe are capable of render-

ing occasionally good service, they only constitute particular methods which cannot replace X-ray examination and the extraction by means of the intermittent control and that their use can only be restricted to hospitals which have no X-ray installations. These hospital units become less and less frequent; we therefore find that the use of these methods does not extend, but on the contrary becomes daily restricted.

However, it is as well to know of their existence in order to be able to use them in case of necessity when nothing better is available.

CONCLUSION

We live now in such times that the memories of the pre-war epoch become more and more blurred. To-day we must imagine that there was such a time when surgeons were trying to find projectiles without having X-rays at their disposal.

We have shown here what services they are rendering us daily in the search for projectiles known or suspected.

Very often a projectile which has not been detected persistently causes inexplicable symptoms; but the rays detect it and the operation is carried out without difficulty.

Very often also a radioscopic examination discovers by chance the existence of ignored and inert projectiles. There is no doubt that these have remained from former wars and nevertheless many of these wounded recovered. This tolerance of the organism must not be forgotten. It is therefore a matter of dispute whether inert projectiles should be extracted. It should only be taken into consideration if the damage caused by the operation is going to be less than the inconveniences felt by the patient.

But how can we appreciate the possible damage unless the rays have enabled us first to localise the projectile, then to estimate its exact depth, and to locate its precise anatomical situation? It is only in the light of this knowledge that the advantages or inconveniences of the extraction of the inert projectiles can be properly weighed.

Finally the rays do still more. They guide the surgeon in his search, they lead him to the metal body by the most direct and most favourable way, according to his choice, with the smallest damage and without any risk of failure.

We have seen the real aid which may be given to us by electro-vibrators, but also the very frequent cases in which they are not successful. The rays are an infinitely truer and surer guide.

The first idea which must have come to the surgeon was to look himself at the screen, and to put on himself the fluoroscope, to go and grasp with forceps which he saw a projectile which he also saw. But then he was working in the dark and was receiving harmful rays to a great extent. The simplicity of the process is only apparent and the surgeon has no right to risk damaging his hands to no purpose.

Thus, from the very beginning of the war, it became apparent that only the intermittent control could supply exact information without interfering with the success of the operation itself and without any danger of dermatitis : these controls were effected by the radiologist who became the collaborator of the surgeon.

It is the radiologist who sees and points out. Sometimes he fixes the memory of the position of the projectile with a compass, and during the intervention he utilises it in order to control, in an indirect and intermittent way, the direction of the route of access. The compass is a mediate indicator ; the indication supplied by it is second hand ; the apparatus remembers only after having been placed in the presence of markings the place of which is determined by a graphic method. The position of the projectile thus supplied is relative only, dependent on the position of the marking points.

On the contrary, the radiologist looks at the projectile directly on the screen and shows it with the end of his needle : " That is where it is," he says. The information is immediate and first hand. Its value is absolute and not only relative. It is not the control with two degrees of the compass, it is direct control.

It is the second mode of intermittent control which we consider superior to all others, because it is simple, because it avoids all causes of errors, because it is without danger : *cito, tuto et jucunde.*

It does not matter that some people use it exclusively, that others continue to make use of the compass, but operate on a radiological table, ready to utilise the intermittent control of the screen in case of failure : it nevertheless remains a fact that only that last system of control gives the surgeon a complete guarantee against an unsuccessful operation.

For many long months we have been trying to perfect and to make its method of working more precise. Numerous and eminent surgeons have come, sometimes from very far, to see us operate. All have recognised the advantages which our method of working presents.

It seemed to us that we would do useful work by describing this method in a more lengthy way than in our various communications and by publishing to-day this volume where we have condensed what we have learned at the hospital of the Descartes Lyceum during our radio-surgical collaboration.

SECTION II
ARTIFICIAL LIMBS

ARTIFICIAL LIMBS

CHAPTER I

GENERAL CONSTRUCTION OF AN ARTIFICIAL LIMB

A PROSTHETIC apparatus for any amputation is composed of two parts :

1. The artificial limb.
2. The attachment of this limb to the trunk.

The artificial limb itself is divided into two parts :

1. A conical socket.
2. A part which replaces the missing limb and is in fact a terminal functional appliance.

Two conditions must be considered, whether or not there remains attached to the trunk a segment of the limb capable of being fitted into the base of the artificial limb, to which it gives support, and to which, in addition, it can communicate movement. Accordingly the artificial limb differs essentially for :

1. Disarticulation of the shoulder and of the hip.
2. Amputation of the arm and of the thigh.

In the first case we attach to the trunk an instrument which is entirely passive.

In the second we attempt to turn to account the active movements of the stump.

These various parts do not lend themselves to

a general description applicable at once to the upper and lower limbs. Not only are the modes of attachment and the functional artificial limb quite different, but the bucket does not serve the same purposes.

The position of the scar.—The stump, which fits the bucket exactly, transmits to it two kinds of force:

1. The force of vertical pressure.
2. Lateral force corresponding to the angular movements of the joint above.

The lateral force is transmitted by the whole of one surface of the stump to the corresponding lateral surface of the bucket: by the anterior and posterior surfaces only in the case of hinge joints such as the elbow and the knee: by all surfaces in the case of joints with movements of circumduction such as the shoulder and the hip.

Vertical pressure exercised upwards or downwards may cause the limb to press upon the bucket at two points: (1) on the summit of the cone, *i.e.* on the extremity of the stump; (2) on the base of the cone, *i.e.* on the bony prominences around the last remaining joint. The adjustment is never sufficiently accurate for the relief due to the fitting of the stump in the bucket to be of much importance.

We should take it as a general rule that a scar cannot stand pressure or friction; and that in consequence, when we amputate under favourable conditions, we should arrange to place the scar in such a position that from our knowledge of the suitable prosthetic apparatus these two evils will be avoided. It should be added, however, that after perfect primary union, the narrow and mobile scar is very tolerant, but it must also be remembered—

especially as will be seen in the lower limb—that this condition is rarely realised in war surgery.

The length of the stump is often estimated by reference to that of the other limb; amputation at the upper, middle, or lower third of the thigh, of the leg, of the arm, or of the forearm. This is convenient, starting from a certain minimum length, but there is an *absolute minimum length* below which the stump has insufficient leverage and tends moreover to escape from the bucket.

Temporary and permanent apparatus.—For the irregular amputations of war surgery which have suppurated, more often than for those of civil practice, it is generally advisable, particularly in the lower limb, to use a temporary apparatus, of fairly good fit, for several weeks or even months before the permanent apparatus of more precise fit. The stump has to soften and shrink gradually; only when this has occurred can we make an accurately fitting bucket, by means of a cast if necessary.

Materials for making the bucket.—The first method of construction is that of *leather reinforced with metal;* a sheath strengthened with metal supports, is laced around the stump; the supports further give attachment, if there is room, to the artificial joints. This is an excellent principle, either for stumps which are still likely to diminish in size, or for the upper limb where exact fit is of secondary importance.

For buckets accurately fitted on a cast we employ:

Blocked leather, which loses shape and ought to be abandoned for artificial limbs for the lower extremity.[1]

[1] This we have attained at the *Fédération des Mutilés*, having forced the makers to abandon their routine. It seems to us therefore that the same result might be attained for the appliances furnished by the State, which are still made of leather.

Celluloid is the material of choice, but it has the defect of requiring the hand of an artist; commercial attempts on a large scale have so far yielded mediocre results.

Metal (zinc, sheet steel, aluminium), the defect of which is that the apparatus, particularly for the lower limb, is noisy. This is also an inconvenience in the metal joints of lateral steels of leather appliances and of the spiral springs in certain wooden apparatus, for this reason indiarubber is more often relied on for springs and accumulators.

Wood, for many years used for the commoner types of limbs for the lower extremity, is now, as the result of American influence, utilised for the making of apparatus hitherto termed "de luxe," but to-day serviceable, thanks to this technique.[1]

The adjustment to the stump is very exact; the contact with the surface where there is friction is soft and comfortable without padding; the appliance is light, strong and silent. The best woods appear to be English willow and lime. The bucket should not present any flaw or knot, this can be seen on the inner uncovered surface.

But we must emphasise the general fact that *standardisation is impossible when the bucket is made of*

[1] Working in wood, to hollow out of a log of wood a bucket which fits the stump accurately, is no novelty. Some sixty years ago two Frenchman, Bailly, then Xavier, succeeded in such construction. But these appliances, like the common, cheap unshaped peg leg, split easily and were only made strong when the Americans conceived the idea of covering the outer surface with a layer of raw hide: strong, and therefore practical, for though we may resign ourselves to the frequent renewal of a peg leg at 25 francs, it is another matter with an appliance costing 300 to 400 francs. (Prices in peace time.)

(In England the standard patterns of artificial legs have for many years been made out of wood.—Ed.)

wood. For the other parts it is possible but not for the bucket, which must be made specially for each patient, hollows being made for each bony point, which must be marked out and felt for with the fingers. A plaster cast would appear more exact: but by this means we do not mark out the bony points. Good results cannot be obtained, if, as certain people have tried, linear measurements are sent to a workshop whence an apparatus is forthwith despatched to a patient whom the maker has never seen.

CHAPTER II

GENERAL PRINCIPLES OF FITTING FOR THE LOWER LIMB

WHETHER we are dealing with an amputation of the leg or an amputation of the thigh, the principle function of the artificial limb is to support the weight of the body. The bucket must therefore give support to this weight. Three bearing points are thus possible : at the base, upon the surface and upon the end of the stump.

1. *Bearing upon the base.*—The principal bearing is that which is taken by fitting the upper edge of the bucket under the bony prominences situated around the last joint preserved, *i.e.* the tuberosity of the ischium for the thigh, the head of the tibia for the leg.

2. *Bearing upon the surface of the stump.*—Certain makers attribute to this an importance which we believe to be imaginary, but which leads them to erroneous conclusions.

It is evident that if a conical stump which is jointless and which transmits the weight is fitted exactly, point downwards, into a conical bucket, supported below by a vertical pillar, the weight is transmitted by the friction of the part enclosed against the bucket, without any pressure upon the free end.

Whence it may be concluded that, as the end of the stump should not serve as a bearing point, we should prefer a terminal scar to lateral scars which might be rendered painful or even ulcerated by friction against the bucket.

But experience shows us that if the pressure of the bucket at this point is harmful to the lateral scars, it is not less so for most terminal scars.

The stump in its bucket is in fact a bone, furnished with soft parts upon which we cannot exert vertical pressure, without squeezing them back towards the base of the stump, thus exerting an upward tension of the terminal soft parts over the end of the bone. This is bound to occur unless there is a considerable length of soft parts beyond the end of the bone, that is unless more bone has been sacrificed than was necessary. In this way we get all the disadvantages of an end bearing without its advantages.

3. *Direct end bearing.*—This is only the principal bearing in certain special stumps which we shall indicate in due course ; in some of these it is the sole bearing. In the case of apparatus for the usual amputations, above the epiphyseal enlargements, it is never more than a complementary or accessory bearing, although a very useful one.

To take pressure upon the end of the stump it is only necessary to stretch across the bucket at the right height a piece of material covered with felt. If the apparatus is made of leather, the support is taken upon a circular band of metal fixed to the lateral steels.

In order that direct pressure upon the stump may be possible, two conditions are indispensable : that there is no terminal scar ; and that the extremity of the bone is well covered with a thick and non-

adherent flap. Actually walking directly on the stump does not involve simply support by pressure, but also inevitable friction, of greater or less importance, caused by the backward and forward movement. This is only realised under the most perfect conditions if the skin is adapted by its structure to this movement. This is the case with the sole of the foot: where the epidermis and dermis are thick and the subcutaneous areolar tissue and deep fascia, continuous with it, enclose little cavities filled with lobules of fat; these form a cushion, like little globules of liquid gliding over each other. The skin of the point and of the posterior surface of the heel is less suitable anatomically than that of the sole: it is, however, good, and it is for this reason that after amputation above the malleoli, it is possible to walk directly upon the cut surface of the tibia.

Nevertheless skin which is not prepared in this way by its normal structure can adapt itself to pressure and friction, provided that it is padded by a thick muscular layer, sheathed whenever possible with fibrous tissue. A skin which is not so lined, especially in fair and stout people, with thin and delicate skin, ulcerates easily as the result of friction or even of simple pressure, and bursæ and callosities form. See what happens to the skin on the dorsum and outer side of the foot in the case of talipes equino varus. The muscles of the flap will not remain over the bone in the condition of muscular tissue, they become fibrous—but they are useful because:

1. They interpose a fibrous layer of greater or less thickness between the bone and the skin, so that the latter remains movable over the end of the bone and is not directly compressed;

2. They adhere to the cut section of the bone forming a tendinous insertion, which renders their action on the bony lever more powerful.

A flap bears weight badly when the muscles have retracted around the bone, over which there is then nothing but skin. It is the same when the flap is stretched tightly across the end of the bone, *the soft parts must remain soft and free.*

Among the hundreds of cases of amputation of the leg or thigh that have passed before us in being fitted at the *Fédération des Mutilés*, there were many in which the presence of a terminal scar rendered the fitting of an apparatus difficult; we have never found this the case with a lateral scar; we have never seen the latter ulcerate rapidly as the result of pressure or friction in a properly made wooden bucket. So that it cannot be admitted that the proper covering of a stump is ever a matter of secondary importance.

Consequently we should consider, as a matter of principle, the circular method of amputating only as a last resort, and we ought to arrange the section of the soft parts so as to cover the end of bone as adequately as possible, and to bring the scars to one side.

We realise that in practice war surgery often necessitates deviations from the ideal. We often find ourselves in a dilemma—either the stump must be good but too short; or, being long, must be poor or even bad.

In the special case of the thigh, circular amputation in the lower third when it is carried out through healthy tissue and has not suppurated can be trimmed and sutured in such a way as to give an excellent scar, which is transverse and slightly posterior. In

this situation after these routine amputations, a linear scar which is supple and has healed by first intention, separated from the bone by a good cushion of muscular and fibrous tissue, causes little embarrassment, whatever its position; at the end of a few months it stands pressure and friction without harm. But we are considering war surgery and consequently we are often called upon to fit stumps in which the cicatrix is large, hard, and more or less irregular, in which the bone has suppurated and in which the neighbouring soft parts are indurated and scarred. These stumps are not, however, the results of the work of the worst surgeon.

Amputating through infected parts, resigning himself to healing by granulation and subsequent trimming by operation, he must take time and trouble to attain in the end a result which is good functionally, although at first sight unsightly. But it is this surgeon who is on the right road, rather than he who sends us good stumps which have not suppurated, because he has amputated through the thigh for a wound of the middle of the leg, or through the leg for a wound of the foot or even of the front of the foot.

It is clear, that for the stump effectually to play its part of a lever in its bucket, a certain definite length is necessary; and we ought to do everything possible to secure a length of at least 15 to 20 centimetres in a thigh stump, or 10 to 12 centimetres in a leg stump. But when this length is secured, there is no great functional difference between, for example, an amputation of the leg in the lower third or in the lower quarter, particularly if the fitter understands how to utilise direct end bearing. The

knowledge of this is of capital importance to the surgeon called upon to carry out secondary operations upon imperfect stumps, in determining whether it is possible to put an immediate stop to suppuration by drastic shortening, or whether he must preserve length and lose time by curretting the foci of inflammation in the bone.

CHAPTER III

ARTIFICIAL LIMBS FOR AMPUTATIONS THROUGH THE THIGH

THERE are two entirely different modes of fitting :

I. For amputations above the condyles, in which weight must always be borne upon the tuberosity of the ischium through the top of the bucket.

II. For amputations through the condyles (or for disarticulation of the knee) in which a direct end bearing may suffice.

I. Apparatus with Bearing upon the Ischium

(*Amputation above the condyles.*)

In the construction of an artificial limb for amputation through the thigh two entirely different principles may be used, according as it is desired to make the patient walk upon a rigid shaft, that is to say upon a peg, or upon an artificial leg proper, in which the knee bends in walking (known as the American leg).

But whichever principle is adopted, whatever material is chosen, wood or leather, and however exact the fit in the bucket may be, certain common rules govern :—

1. The shape of the top of the bucket by which

it is fitted to the top of the thigh and its bearing upon the ischium.

2. The attachment of the limb to the trunk.

To begin with we shall consider these two questions, and then temporary and permanent apparatus, the peg leg and the full artificial limb, will be described.

I. The Shape of the Top of the Bucket

The tuberosity of the ischium is the sole bony point which can prevent the ascent of the limb when weight is applied. This tuberosity is situated in the posterior part of the perineum (Fig. 1), the anterior part of which is unable to stand pressure. It is necessary, therefore, to clear this part by cutting down the inner border in its anterior part, forming a *perineal concavity*, which rises posteriorly against the ischium (Fig. 3).

It is essential that the ischium should not be able to slip inside the bucket, otherwise the inner border will come in contact with the perineum: therefore the diameter of the bucket must be less than that of the limb, so that the ischium may rest upon its upper edge.

If the bucket is too large, the patient abducts the stump, so as to lower the inner border and prevent pressure on the perineum; he carries the leg away from the side as he walks, and this is both unsightly and fatiguing.

When an apparatus is completed, it is very easy to ascertain the site of the pressure on the ischium. The limb being put on, the ischium is fixed between the thumb and first finger, and it can then be ascertained whether it rests on the edge of the bucket or

lies within it. This can be determined more exactly, if whilst the fingers which mark the position of the ischium are kept within the bucket, the patient is told to raise his stump.

If the bucket is sufficiently narrow, it may be circular without the excavation for the perineum (Fig. 2). But this shape is unsatisfactory for another reason, because it results in a tendency for the limb to rotate inwards.

At the moment when the artificial limb is coming in contact with the ground as it takes a step, the pelvis is oblique (the iliac spine of the sound side lying posterior to that of the amputated side). The sound limb as it executes its step is carried forwards, and the pelvis which was oblique in one direction now becomes oblique in the opposite direction. This movement is transmitted to the femur in the stump, so that the artificial limb turns inwards relatively to the stump. With each step this rotation becomes little by little more perceptible, and after a time the patient is obliged to correct it by turning the artificial limb with his hand.

If, on the other hand, the front of the upper border of the bucket slopes downwards and inwards at an angle of about 45 degrees, when as a result of its weight the bucket turns inwards as the limb is swung, the base of the stump will come against a higher part of bucket; but when the pressure of the weight of the body returns, the stump, being forced into the bucket, will descend again along this slope, that is to say a passive external rotation of the artificial limb will be brought about, correcting at every step the tendency to internal rotation.

The same slope may be given to both edges of the

In the upright position the rami of the pubis and ischium, between which stretches the perineum, slope downwards and backwards at

FIG. 1.

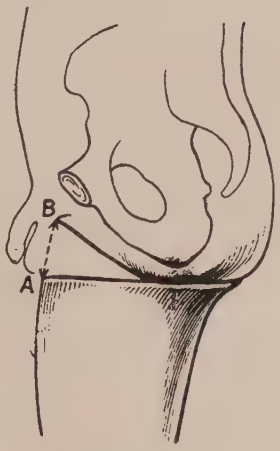


FIG. 2.

an angle of about 45° with the horizontal. The tuberosity of the ischium bounds the perineum posteriorly, and is its lowest point. The rami of the pubis and ischium, corresponding to the genito-crural fold, mark the boundary between the thigh and the perineum. These bones are unable to stand the pressure of an artificial limb.

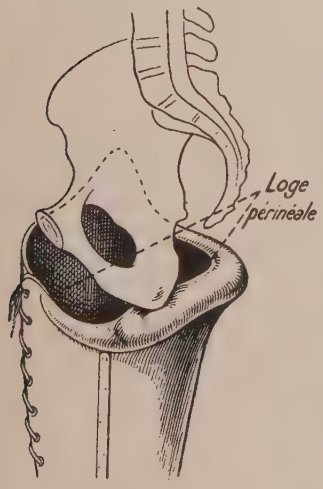


FIG. 3.

If the top of the bucket is narrower than the circumference of the top of the limb, measured below the ischium, it may be circular and still give support to the ischium, which will not slip into it. If the ischium does slip into the bucket, the result will be that it no longer serves as the support, the pressure coming instead upon the rami of the pubis and ischium and upon the perineum.

The constriction thus exerted upon the top of the stump may easily become insupportable. The correct solution of the problem is to cut down the upper border of the bucket opposite the perineum, letting it rise again posteriorly beneath the tuberosity of the ischium, and gain a good support there.

bucket (Fig. 5). This obliquity in the posterior part serves no useful purpose: it is better on the contrary to lower the posterior border combining this semioblique fitting with a rise beneath the ischium and a depression under the perineum (Fig. 6).

These conditions are easily carried out in a well-made wooden bucket, represented in figures 8 and 9, in which it may further be seen that from the front it is convex outwards; from the side, convex forwards (Fig. 9). This form, which is that of some good American appliances, ought to be generally used.

The curve outwards, by drawing away the soft parts from it, frees the region of the ischium and allows the tuberosity of the ischium to press upon the bucket (Fig. 8).

If the thigh piece is curved forwards, and particularly if the limb is built with a very slight flexion of the knee, the stump remains slightly flexed at the hip and the patient feels as if he is sitting in the apparatus.

When the thigh piece is straight, an uncomfortable pressure is produced by the edge of the bucket against the ischium. It may be added that extension of the hip is very often impaired, particularly in patients with a short stump: The extensor muscles being divided, the flexors cause contraction into a flexed position, the more so the shorter the stump is. If the thigh piece is straight, the short stump cannot follow the movement of extension necessary in walking; it slips out of the bucket if the anterior lip of the latter is too low.

The principles are the same for the leather bucket, known as the *French pattern*.

In this the thigh piece is strengthened by two lateral steels (to the lower end of which is fixed the

Figure 4 shows the circular bucket (almost always too large) of the poor man's peg leg, attached to the body by a belt which is fastened to a projection upwards from the outer side of the bucket.

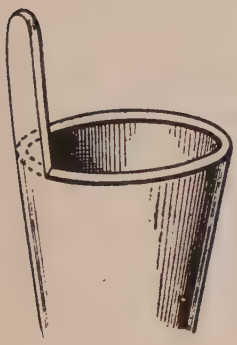


FIG. 4.

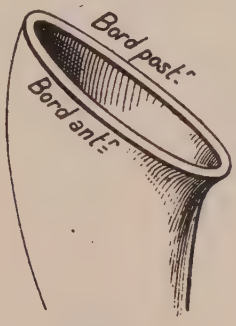


FIG. 5.

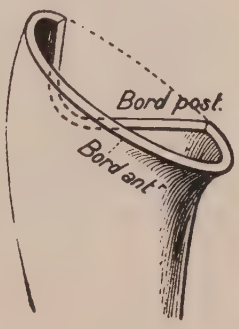


FIG. 6.

Figure 5 shows the oblique bucket, with symmetrical anterior and posterior borders. Figure 6 one with the anterior border oblique, the posterior border being cut away. Figure 7 shows the double

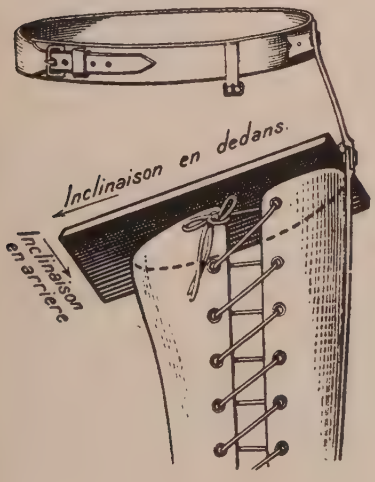


FIG. 7.

FIG. 8.

FIG. 9.

obliquity, downwards and backwards, of the bucket. The convexities of the bucket and thigh piece, in the type which we consider to be the best, are shown in figure 8 (convexity outwards), and figure 9 (convexity forwards).

leg piece) joined posteriorly by a semicircular cross piece on which the ischium should rest (Fig. 13).

The usual form hitherto has been that shown in figure 10. The cross piece was horizontal and formed simply a posterior semicircle; the lateral steels were straight. Consequently in this pattern these steels form a cone, in which the soft parts are not compressed on the inner side, nor drawn outwards, as in the apparatus previously described. Further, as long

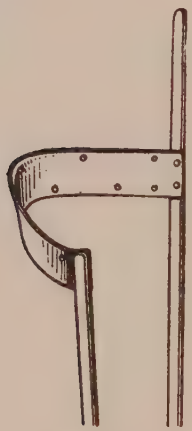


Fig. 10.

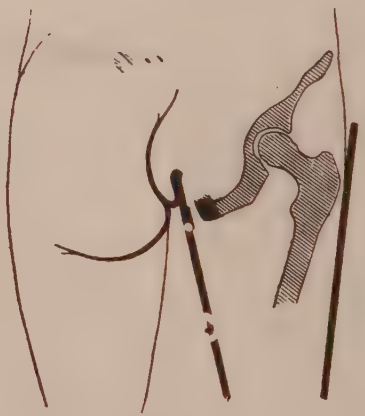


Fig. 11.

as the stump is not shrunken, the ischium covered on its inner side by soft parts sinks into the bucket, and it is the perineum which becomes the point of pressure (Fig. 11). Made of leather, the perineal concavity soon loses its shape and really no longer exists. Finally the bucket is circular, with the faults inseparable from that shape (Fig. 12).

In cases where it is felt necessary to employ leather, all these faults are easily corrected, by giving the cross piece the shape which we have described for the wooden bucket, and by prolonging it forwards

through two-thirds of the corresponding circumference, in the shape of an oblique bucket. (Dotted line in Fig. 12.)

If it is not strengthened, an oblique border of leather gives way, and after a few months' use allows rotation. The leather which extends from the termination of the metal ascends very steeply towards

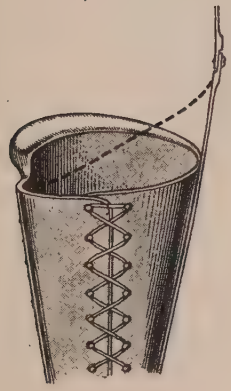


FIG. 12.

FIG. 13.

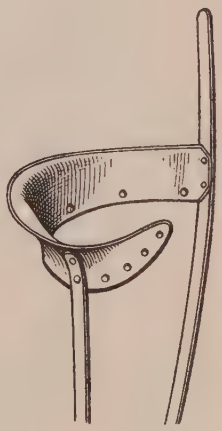


FIG. 14.

The ordinary leather bucket is mounted upon two lateral steels, which are joined by a posterior cross piece (Fig. 13). This framework is shown in figure 10, and covered with leather in figure 12. If the lateral steels are straight and divergent, this has all the defects of the straight circular bucket. The concavity for the perineum, cut out of the leather, soon loses its shape. It is, however, easy to shape the cross piece as shown in figure 14, with a perineal concavity and the anterior border oblique, following the dotted line in figure 12. By doing this and curving the steel uprights appropriately, the correct form of the wooden bucket can be copied exactly in a leather and steel apparatus. Such a correct apparatus is shown in figures 15 to 18.

the trochanter, whilst the posterior border of the bucket, which is horizontal, curves downwards on the inner side to form the perineal concavity.

In figure 14 is seen the metal framework; in figures

15 and 16 that of the apparatus covered with leather; in figure 17 the support upon the ischium; and the

Fig. 15.

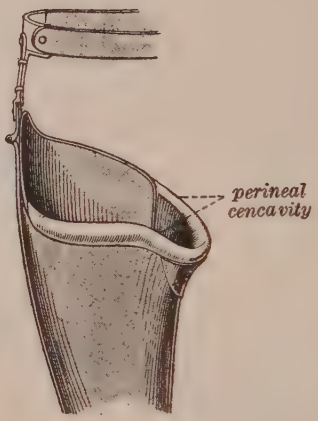


Fig. 16.

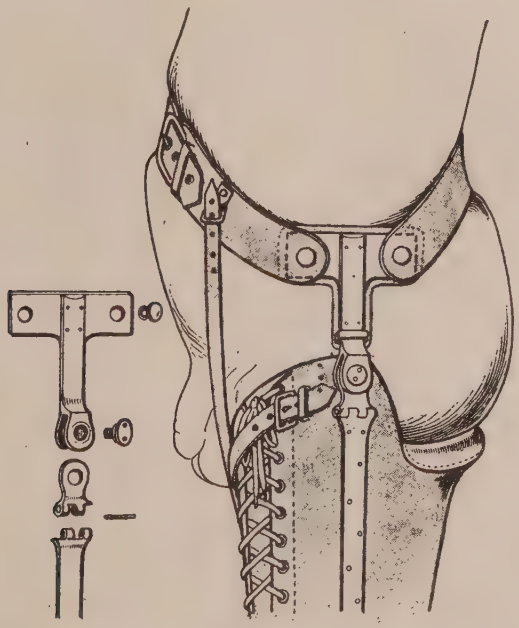
Fig. 17.

Fig. 18.

possibility of making this appliance identical with the wooden bucket will be observed (Fig. 18).

II. Mode of Suspension

Suspension of the thigh piece is essential, and is all the more important when the stump is short and consequently more liable to slip out of the bucket. For this purpose support may be taken either from the waist, upon the *prominence of the iliac crests*,



Figs. 19 and 20.—Simple pelvic suspension, with details of the joint at the hip.

or from the *shoulders* by means of braces. In the case of a long stump (amputation below the middle of the thigh) only one of these methods is necessary, we shall describe the usual methods :

The waist belt (French system) for leather appliances.

Braces (American system) for appliances of wood.

If the stump is short a combination of the two methods is best.

A. Suspension by means of a waist belt.—*For the peg leg made of leather* the best method consists in placing a pelvic plate, which is attached to the hip steel, below the iliac crest (Figs. 20 to 24). A belt attached to the extremities of this plate surrounds the pelvis and passes above the iliac crest on the other side. The thigh piece is attached to this support, on the outer side, by articulation of the outer femoral steel with the hip steel; on the inner side, by a perineal strap. Braces complete the method of suspension of the apparatus (Fig. 21).

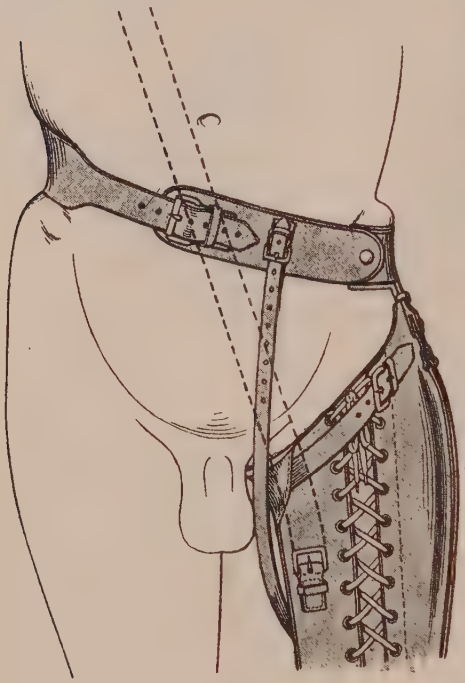


Fig. 21.

The axis of the metal joint between the outer femoral steel and the lower end of the T piece should be directly above the great trochanter (Fig. 20).

The femoral steel often breaks in the neighbourhood of this joint (Fig. 23); we have got over this difficulty by adding immediately beneath it a joint which allows of abduction (Fig. 19). A perineal strap limits this movement.

Suspension from the pelvis.

A metal hip piece is fixed below the iliac crest and held in place by a belt which passes above the iliac crest of the opposite side (Figs. 20 to 24). This piece is attached to the thigh bucket by a joint shown in figure 19 (see also Fig. 22), which allows both flexion and abduction of the hip, and which forms the suspension of the outer side of the limb. The inner border is suspended by means of a perineal strap, shown in figures 21 and 22. In figure 21 is shown how a suspending brace may be easily added. Figure 23 shows the action of a single hinge joint, allowing only flexion and extension at the hip joint. On page 407 will be seen similar joints which, however, move on the pelvic attachment as well as on the thigh piece. The object of this is to prevent the pinching of the abdominal wall by the top of the thigh bucket when the patient sits. It is indispensable in short stumps. On page 21 will be seen a joint which allows abduction of the hip, and thus relieves the strain upon the hinge joint; without it the latter is easily broken.

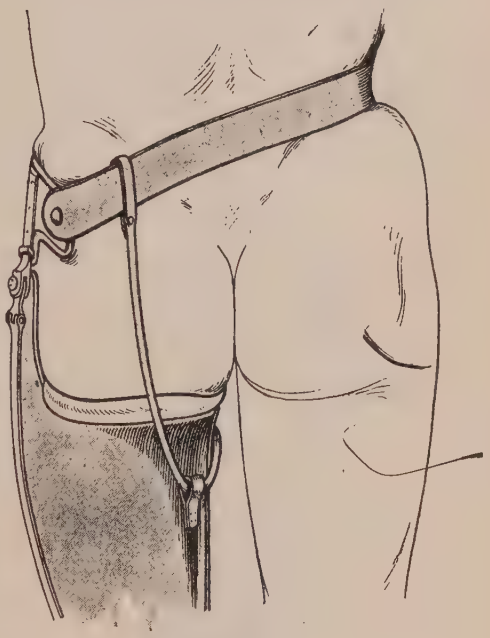


FIG. 22.

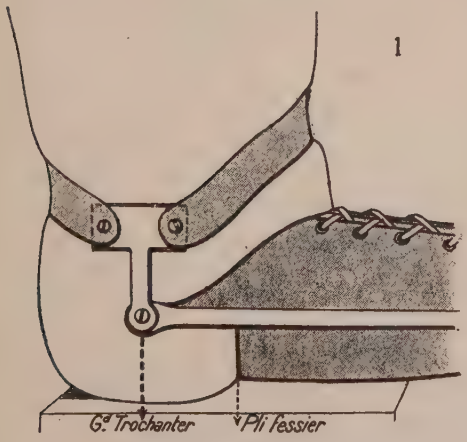


FIG. 23.

B Suspension by means of braces (American method).—The American method of suspension has the advantage of leaving the pelvis free; the patient does not feel the pull of the hip piece. Besides, when the belt is used, if the patient sits down, the buttock on the side of the stump is raised, to an extent corresponding to the thickness of the bucket, an

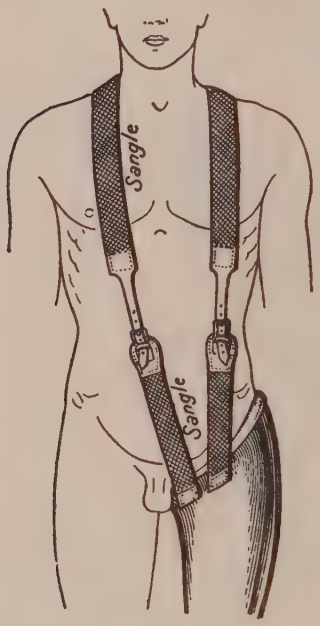


Fig. 24.

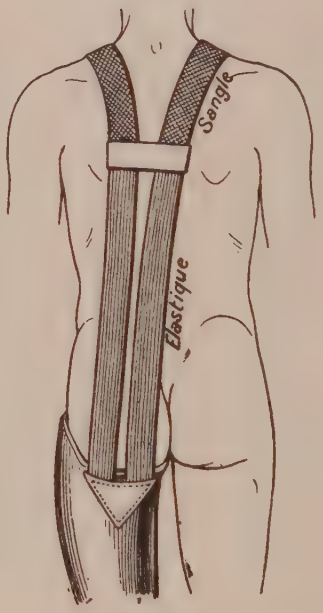


Fig. 25.

Braces composed of straps passing over the shoulders and down the front, attached to the bucket by buckles. Posteriorly they are joined together by a cross strap between the scapulæ, and beyond this are continued in the form of elastic straps.

obliquity of the pelvis, which is both uncomfortable and unsightly, being produced. The braces being relaxed in the sitting posture, the patient can avoid this inconvenience; for the stump may be slipped partly out of its bucket, the upper extremity of which is then beyond the level of the edge of the chair. This

position is very comfortable, because it is normal, but the patient must replace his stump in the bucket whenever he stands up.

This form of suspension is essential for those artificial limbs with a free knee-joint, in which, as we shall see, the braces serve to extend the joint.

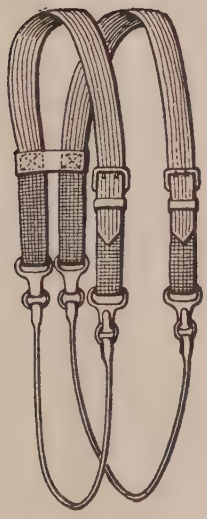


Fig. 26.

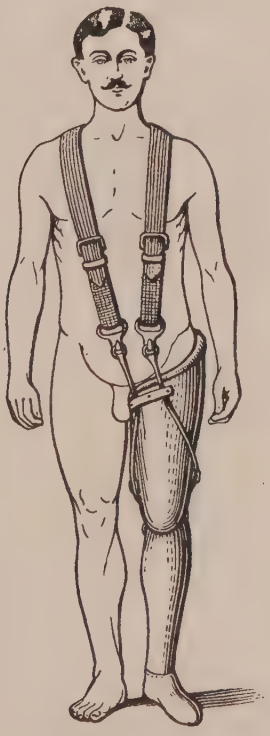


Fig. 27.

Fig. 26.—Braces which end below in looped thongs of leather.
Fig. 27.—These loops, held in to the thigh piece by passing beneath a loop of leather, pass over two pulleys about the middle of the inner and outer sides of the thigh piece respectively. The outer brace tends to abduct the limb if it is tightened.

We illustrate here two methods of attaching the braces to the thigh piece, that which we use in the limb supplied by the Fédération (Figs. 24 and 25)

and that which is used in the American limb of Marks (Figs. 26 and 27).

C. Combined method of suspension.—*If the stump is short* the artificial limb must be attached both by a belt and by braces; the latter should be 5 to 6 centimetres wide.

In these cases also, to prevent the stump escaping

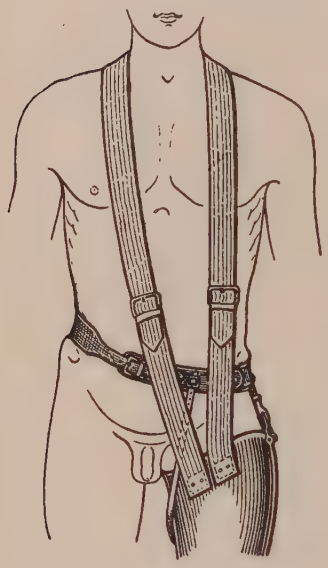


Fig. 28.

Combined suspension for short stumps.

Fig. 28.—Complete appliance.

Fig. 29 and 30 show the value of a flexion pivot between the hip piece and the pelvic plate. If there is no such pivot, the T piece undoubtedly rotates upon the belt, but not to a sufficient extent to prevent the thigh piece in rising and pinching the abdominal wall (Fig. 29). If there is a double joint the hip piece becomes oblique, thrusting the thigh piece forward and allowing the patient to sit erect (Fig. 30).

from the bucket when the hip is flexed, the front of the thigh piece is carried as high as possible; but if the appliance is furnished with a metal T piece, such as has been described (Fig. 29, see also Fig. 23), then this raised border prevents flexion of the hip by coming in contact with the abdominal wall when the patient sits down. This difficulty can be got over by making the top of the T piece movable; when the patient sits down the vertical piece of the T becomes oblique, the thigh piece comes forward, allows the stump to escape a little way and no longer presses against the abdominal wall (Fig. 30).

The belt may also be replaced by a leather corselet,

having fixed to it the hip piece that we have just described.

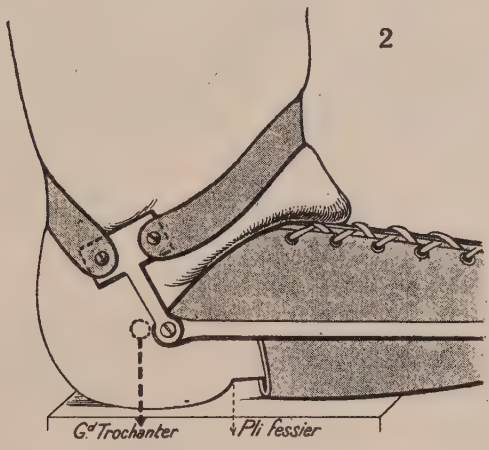


FIG. 29.

The braces by themselves are a poor method of attachment for a short stump.

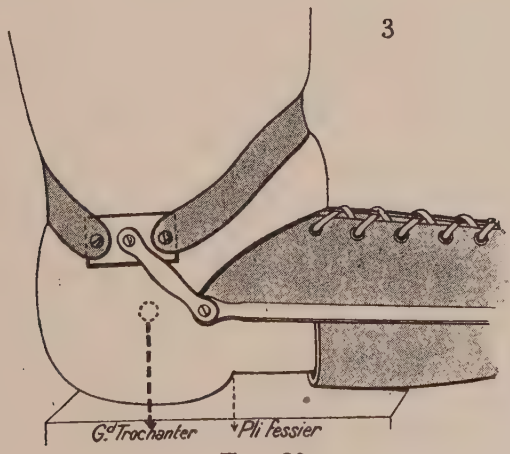


FIG. 30.

In the sitting position the stump easily escapes from the bucket.

When the patient is standing the stump remains abducted, whilst the apparatus, as the result of its own weight hangs vertically, in this swaying position the lower extremity of the stump presses against the outer side of the bucket, whilst the inner edge of the bucket cuts into the flesh at the top of the thigh.

III. Walking on a peg leg and similar appliances

The rigid peg and the jointed peg.—The peg leg is a rigid rod, ending in a slight enlargement, which transmits the weight of the body, resting by means of the ischium upon the top of the bucket, directly to the ground.

The erect position is thus very secure, and stability in walking is also very good throughout the time when the artificial limb bears the weight.

To raise the limb from the ground and carry it forwards, the patient uses at the same time both flexion of the stump at the hip and movements of the pelvis (elevation, then rotation inwards) varying to some extent with his proficiency and with the length of the stump.

The old-fashioned peg leg, called the "poor man's peg," consists of a bucket continued into a rigid peg. If the support beneath the ischium is well made according to the principles described above, it is an excellent temporary limb.[1] This bucket of common wood, which is not specially shaped to the stump, is very economical; its imperfect fit is an advantage

[1] A number of temporary limbs have been designed, with buckets of lattice work or of plaster. The old-fashioned wooden peg, which is easily obtained, avoids all this additional work without any disadvantage.

in that the stump, which is still enlarged, cannot bear friction ; as the stump assumes its true shape and diminishes in size, the bucket is packed. We would add that every patient, who is not rich enough to possess two complete artificial limbs should have in reserve an emergency peg leg, for occasions when the artificial limb requires repair.

As a permanent apparatus, with accurately fitted bucket, the rigid peg leg has two defects : it has not the appearance of a leg and foot, and when the patient is sitting the rigid peg is unsightly and inconvenient to him and to his neighbours. We have therefore designed and completed a *jointed peg leg*, the principle of which is as follows :

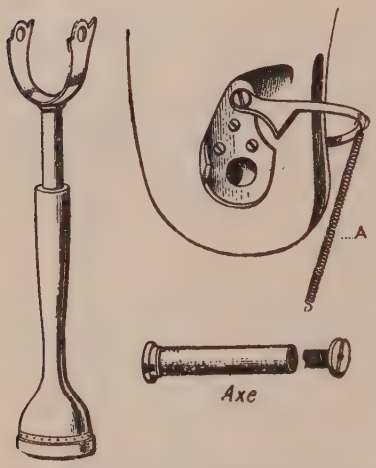
Below the thigh piece the peg is attached by a transverse joint, this joint being locked in the extended position when the patient is upright. The patient sets it free by manipulating the lock through the trousers, when he sits down ; when he gets up again the locking in the extended position is automatic.

The fitting of this transverse joint may be carried out in two ways.

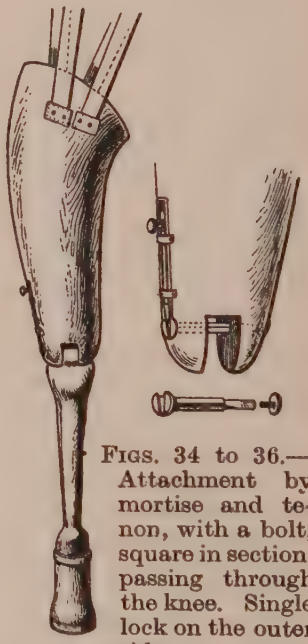
1. The upper end of the peg ends in a stirrup-shaped fork and the bolt passes through the two ends of this fork and through the lower end of the thigh piece (Figs. 31 to 33).

2. The lower extremity of the thigh piece has cut in it a central mortise into which fits a vertical plate, prolonged upwards from the middle of the leg piece. The bolt passes through this artificial tibial spine and through the two sides of the mortise in the thigh piece. If the hole in the tibial spine through which this bolt passes is square the hinge works securely (Fig. 34 to 36).

In this form the axle turns with the leg, in the first form this is also possible. But most often when the forked attachment is used it is fixed to a leather thigh piece, and each end of the fork is jointed independently to the corresponding end of the lateral steels of the thigh piece, without any complete trans-



FIGS. 31 to 33.—Fixation of the stirrup of the leg (Fig. 31) by a transverse bolt (Fig. 33), the aperture for which in the thigh piece is seen in Fig. 32. Double lock (Fig. 32).



FIGS. 34 to 36.—Attachment by mortise and tenon, with a bolt, square in section, passing through the knee. Single lock on the outer side.

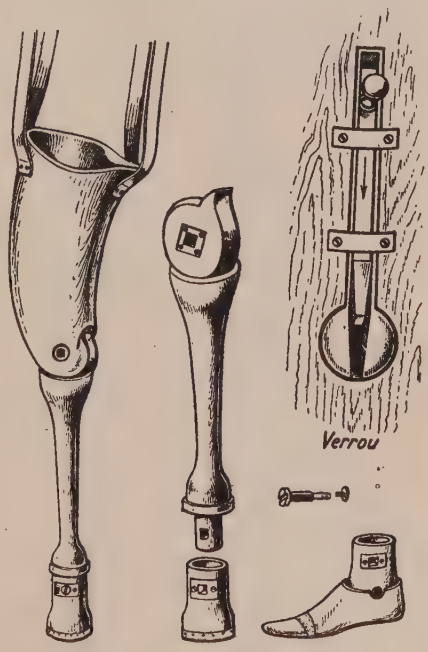
verse bolt. It is then the fork that revolves around these two joints.

If there is a complete transverse bolt, the joint can be securely locked by a single lock at one of its extremities (at the outer extremity) (Figs. 36 to 39).

If there are two lateral joints the single lock is insufficient, both joints must be fixed at once; unless this is done, that which is not fixed has a certain amount of play and is strained.

It is, however, simple, by means of a posterior semicircle, to joint the two locks and to work them together by a single movement (Fig. 32).

For æsthetic reasons the wooden leg piece may be made in the shape of a leg and foot. But if the principle of the peg leg has been adopted, for an agricultural labourer for example, on account of its stability, it is better to use an appliance in which a "*show leg*" is fitted around the simple peg on days when appearance is more important than work (Figs. 37 to 45). The limb is thus rendered lighter, for the false calf consists of a simple layer of felt and it is very easy to replace the enlarged lower end of the peg by a foot.



FIGS. 37 to 40.—Attachment by a mortise, and show foot.

We show later two models of this sort, one with an American thigh piece of wood and a single lock upon a transverse axle, the other with a leather thigh piece and a double lock. The first (Figs. 37 to 40) is shown with an attachment by braces, and the second (Figs. 41 to 47) with an attachment by means of a waist belt; we have already explained when these two must be combined.

Most often the wooden thigh piece is to be preferred;

Leather and steel peg leg, with show foot.

Figures 41 to 47 (leather appliance) should be compared with figures 37 to 40 (wooden appliance) which complete them in certain points. It is unnecessary to refer further to the method of fitting the bucket to the suspension, or to the method of attaching and locking the knee.

The peg—attached above by a stirrup or by a mortise, it does not matter which—ends below in a rectangular tenon which fits into

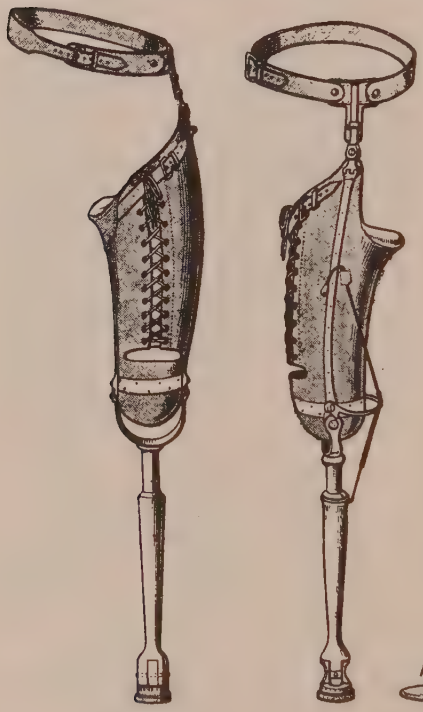
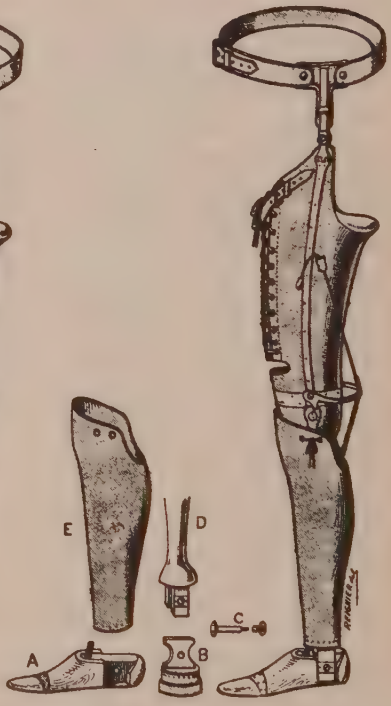


FIG. 41.



FIGS. 42 to 47.

a corresponding excavation in the upper surface of the terminal piece, whether peg or foot (Figs. 38 and 44). A transverse bolt, square in section, with a head at one end and a thread at the other, fixes these two parts together. By taking out this bolt the peg can be replaced by the foot or *vice versâ*.

If the attachment of the foot is made in the heel, a fixed foot is used (Figs. 43 and 45), but it is easy, by making the attachment higher, to use a foot with movable ankle joint (Fig. 40).

The attachment of the show calf piece around the peg is shown in figures 43 and 45.

the limb is lighter and may last four or five years instead of about two years.

We may add that leather loses its shape and the bucket becomes enlarged, producing inconveniences already described on page 398

But *leather*—indespensable for certain stumps which cannot stand a wooden bucket—has the advantage that it can be employed as a *temporary fitting*. During the first weeks, sometimes even for the first months, the shrinking of the stump can be accommodated by lacing up the bucket, and, when shrinkage is complete, the leg part of this first apparatus can be attached to a wooden bucket which the improved condition of the stump now renders possible.

This form is a little more expensive (80 frs.) than "the poor man's leg," but I believe a great deal more comfortable. It may be added, that it is easy when the foot is fitted at the end of the apparatus to render flexion of the knee free and to attain the "American walk," of which we shall speak later. All that is necessary is to attach in front an artificial muscle of indiarubber, reaching from the thigh to the leg and an extending sling like that in the American limbs (see page 427).

This appliance which we call the "Fédération Leg," because we designed it at the *Fédération des Mutilés*, has already been imitated without its origin being acknowledged.

IV. Walking with free flexion of the knee

A. *Design.*—The oldest type, which will suffice for studying the general conditions of stability, is that

of Marks, with a fixed foot shaped out of the same piece of wood as the leg: the ankle joint—several types of which we shall describe later—does not affect the question of stability.

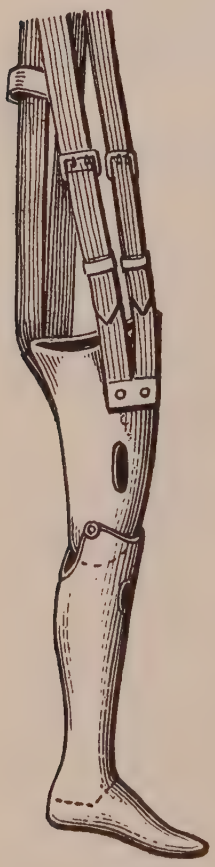


FIG. 48.—Marks leg with fixed foot.

The appliance is made entirely of wood; it is strong and light.

Nothing need be added to the description already given of the fitting and method of attachment of the thigh piece, which ends below in a curved "condyle,"[1] which fits into the top of the leg piece. It is transfixed by a metal bolt, from each end of which a metal plate descends and is riveted into a corresponding groove in the leg.[2] This forms the axle which rotates in the thigh piece when the knee flexes or extends. Flexion of the knee is free. Extension is stopped just short of the straight line (see p. 396).

The foot is in equinus at an angle of 25° to 30° so that the heel is 2 or 3 centimetres from the ground (the usual height of the heel of a boot). The piece of wood which forms the instep and which is continuous with the

FIG. 49.—Construction of the foot.

[1] The bucket and the condylar portion are made of two separate pieces of wood.

[2] The hole through which the bolt passes being cut in soft wood (willow or lime), must be strengthened by a cylinder of metal, of leather, or of harder wood (beech or service tree) in which the axle revolves.

leg stops at a point corresponding to the middle of the metatarsus, and is only half the thickness of the foot. The rest of the foot is shaped of indiarubber stuck on to the instep piece; the wood and rubber being enclosed in a sheath of leather.

The foot should also point slightly outwards, as in the normal standing position.

To ascertain whether the limb is built so as to ensure equilibrium, a thread is stretched against its side so as to pass through the axes of the knee and ankle joints, if this cuts the ischial bearing point at its centre the equilibrium of the patient is assured. Equilibrium will be better still if the cord lies entirely behind the ischial bearing point, leaving in front of it the greater part of the thigh piece. The best method of ascertaining if the foot is properly mounted is to hold the limb in front of one by the thigh piece, with the knee bent at a right angle; it can then be seen whether the foot turns outwards at the correct angle.

It is not necessary to say anything more about the shape of the thigh piece (page 397).

The metal bolt which transfixes the knee must not allow any play; the hole through which it passes must be lined with hard wood or leather.

The indiarubber sole should be reinforced with several layers of canvas incorporated in the rubber, as the latter if not so reinforced perishes and cracks.

The appliance must further be examined after it is applied. The level of the iliac spines must be compared: the spine on the side of the amputation should be 2 cm. below that of the sound side.

Examine the position of the point of the foot. Make the patient sit down, see if the knees are on the same horizontal plane; if the sound knee is the higher

the leg piece is too short. The foot being fixed in the equinus position the patient must wear boots while the examination is being carried out.

B. *Mechanism of walking.*—In walking, a step being taken with the artificial leg, the toe of the foot is the last to leave the ground, the heel being raised and the knee straight. The limb is swung forward and raised by flexion of the hip: active flexion of the knee is impossible, but passive flexion occurs, owing to the weight of the leg piece, as the thigh is raised.

At this moment the leg piece is vertical, forming an angle with the thigh, from this position it must pass into one in which it is oblique forwards and downwards, in a straight line with the thigh, *so that the knee may be fully extended when weight is again borne by the limb* as the foot meets the ground. If at this moment the knee is flexed the limb will double up under the weight of the body.

The first contact of the limb with the ground should be at the heel with, as we have already said, the knee extended. Afterwards as the limb, which at first points obliquely forward and downwards, passes into the vertical position in which it must be at the period when it bears the whole of the weight, this complete extension becomes locked and transforms the limb into a rigid column.

This is brought about as explained on page 428 by mounting the foot in equinus, and we must here describe the methods by which the commencement of the movement of extension may be communicated to the leg so that the heel may be the first part of the foot to touch the ground.

These methods may be termed *knee extending*

mechanisms. They assist the passive action of the weight of the leg.

In fact the recurrence of extension is brought about by a pendulum movement of the leg, which, at first oblique downwards and backwards, swings into a downward and forward obliquity. But this movement is slow (the pendulum which marks one second is one metre long) and incomplete. The patient can make it complete with a little instruction, by extending the thigh slightly as soon as the foot touches the ground.

This may be sufficient if the stump is long; the leverage is good, and while the hip is being flexed a swing can be given to the thigh piece which accentuates the pendulum movement of the leg.

But with a short stump some special mechanism is essential to make sure that extension will be complete, otherwise the patient will be obliged to walk with short and calculated steps, to wait whilst the pendulum action produces extension of his knee and allows him to put weight upon his foot.

C. *Mechanism for starting extension of the knee during the time the leg is swinging.*—There are two methods which are generally combined :

1. Elastic traction by an artificial muscle.
2. The extending sling.

1. *Artificial muscle.*—The action of an artificial muscle made of elastic (noiseless) or of a coiled steel spring, is easily understood.

(a) The simplest method (that which is commonly used for infantile paralysis affecting the quadriceps) consists in fixing an elastic band divided into two slips, one on either side of the patella) between the front of the thigh and of the leg, about the middle of

each. (This is represented in figure 98 in our convertable leg.)

(b) When the apparatus includes the regular artificial knee the makers generally place this mechanism in the interior of the thigh and leg pieces, using methods which are often very ingenious. Of these we illustrate some on pages 420 onwards, with an explanatory description.

In describing these mechanisms, which may be called intra-condylar, it is necessary to speak at the same time of the *stop to limit extension* because, as will be seen, it is combined with the extending spring.

We have already said that rigidity in extension when the limb is vertical is essential, but whilst it is necessary for extension to be *complete* at this moment it is also necessary to prevent the knee being forced into the *hyperextended position*, as this would quickly strain the joint and render the limb useless.

This limitation of extension can be effected quite easily by the tension of a popliteal cord (see page 421 The knee in Marks leg), or by carrying the anterior border of the leg piece upwards in front of the thigh piece so that it impinges against the latter.

This method is not very good because it is noisy.

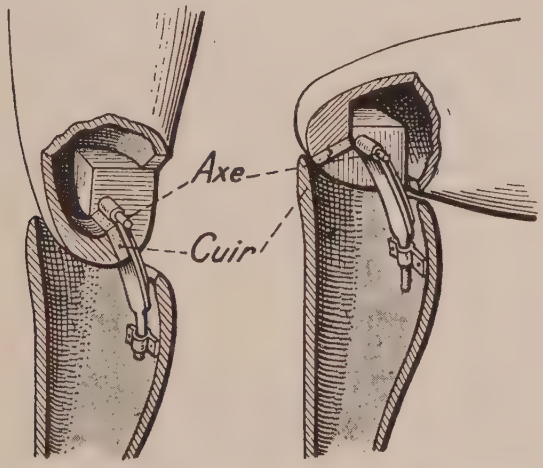
Moreover, the repeated impact against the leg piece may split the wood, so that if this method is adopted the stop must be reinforced by a binding of several layers of parchment.

We will first describe a mechanism the association of which with the extending sling will be seen on page 428

a. *To limit extension of the knee* all that is necessary is to prolong the antero-posterior diameter of the knee bolt (which turns with the leg) by a horizontal wing,

which engages with a corresponding notch in the femoral condyle. We show here (Figs. 50 and 51) a rather more complicated but still simple mechanism which is interesting because it can be combined with the action of the extending sling (see page 428).

It consists of a piece of metal curved on the flat, ending above in a cylinder through which the knee bolt passes, continued below into a cylindrical tail



FIGS. 50 and 51.—Internal mechanism to limit extension of the knee.

piece, which fits into a ring which is fixed inside the top of the calf. During flexion this plate moves in a median posterior window in the femoral condyle, becoming oblique at the same time as the tail piece sinks into the ring; during extension the tail piece rises in the ring and the interior flat surface engages against a corresponding groove in the femoral condyle (covered with leather to secure silence).

β. In the Marks knee an internal system of cords and springs serves at the same time both to limit

extension and to produce an elastic extending force. It is a system which is fairly simple and much used.

1. *Limitation of extension* is secured by a U-shaped cord, the extremities of which are fixed to a wooden cross piece (T), fixed in the thigh piece three centimetres above the axis of the joint. The cords leave the thigh through two lateral openings in the back of the thigh piece, and the loop passes through a ring halfway down the calf.

2. *The extending force* consists in a coiled steel spring the mechanism of which is combined with that of this cord. The lower half of the spring is enclosed in a copper tube lined with chamois leather to secure silence; its upper half or rather more is coiled around a wooden pin, which terminates above in a head which is cup shaped: it will be seen (Fig. 57) that if pressure is made on this head the spring is shortened and under compression.

This spring is fixed below (by means of a tenon which allows antero-posterior movement) upon a bracket in the calf which is continuous with the ring through which passes the check cord. The cup-shaped upper end is in contact with a ball which projects from the upper surface of the thigh piece between the two openings for the check cord (Fig. 53). It will be seen that when the knee is flexed the spring, the head of which lies below the axis of the joint, will be compressed at the same time as the check cord is relaxed) so that there is an elastic recoil tending to reproduce extension. The ball which rests on the top of the spring is fixed in such a manner as to be in the same horizontal plane as the axis of the knee: that is to say, it is in the same vertical plane as this axis when the knee is flexed to a right

The Marks knee.

FIGS. 52 and 53.—O, knee bolt. T, cross piece of wood, situated

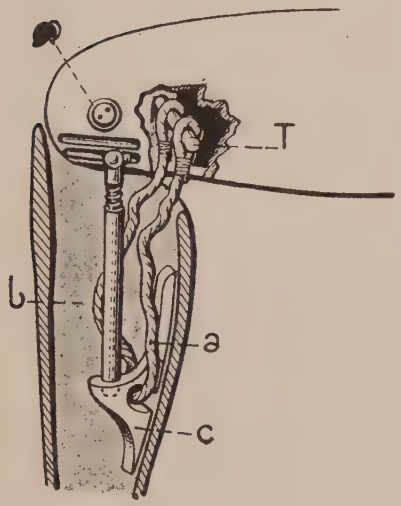


FIG. 52.

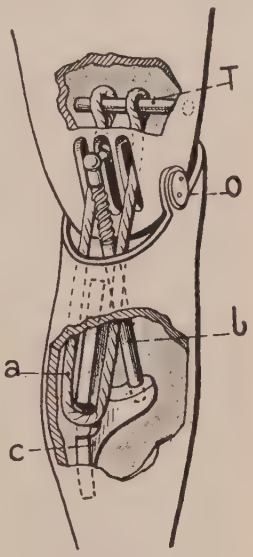
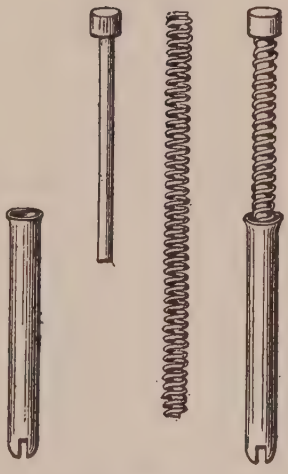


FIG. 53.

in the extended position above the knee bolt, in the flexed position behind it. C, bracket fixed halfway up the interior of the calf.

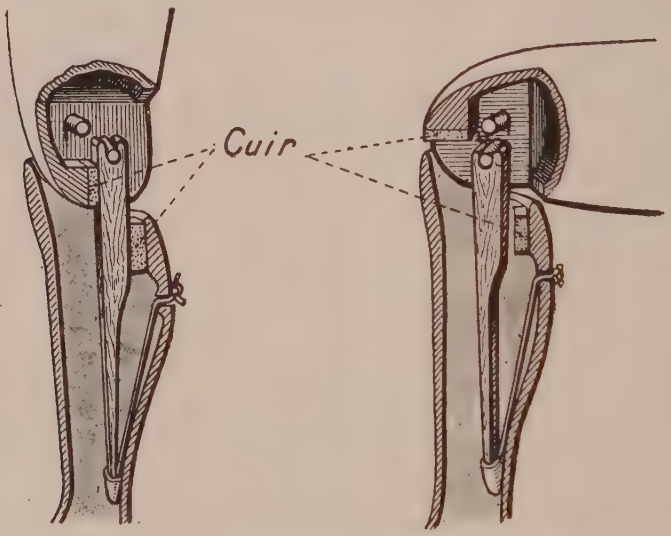
A U-shaped cord *a* passes through a hole in the bracket C and is attached at each end to the cross piece T; it limits extension. The two ends of the word enter the thigh piece by two apertures in the posterior surface, between which is fixed a metal ball which projects 2 cms. The extending spring is the rod *b* which is fixed to this ball and to a socket in the upper surface of the bracket. Figs. 54 to 57 show the parts of this spring: a tube, a spiral spring, and a rod with cup-shaped head. When the spring is in the tube and the rod in the spring (Fig. 57), it will be seen that pressure upon the head of the rod increases the tension of the spring.



FIGS. 54 to 57.

angle (Fig. 52). Therefore in this position the spring has no tendency to produce either extension or flexion, that is to say the mechanism is now at dead point, and when the patient is sitting flexion to the right angle is maintained without any effort.

In the knee shown in figures 58 and 59 the *extending mechanism* is as follows. Directly behind the axis of the joint is a metal crossbar, upon which fits the



FIGS. 58 and 59.—Elastic spring for extending the knee.

grooved upper extremity of a piece of wood, the other end of which rests (like a lance) in a pocket which is suspended in the leg piece by an elastic band (the latter being kept stretched to a greater or less extent by a lace which emerges from the calf).

The elastic being slightly stretched when the knee is extended, it will be seen that the crossbar turning round the axis of the knee becomes lowered as the knee flexes, so that the elastic is stretched and

consequently opposes flexion; but when the knee is bent to a right angle the axis of the joint, the cross-bar and the wooden rod are in the same vertical line; the mechanism is at a dead point just as we have already seen in the Marks knee, and the tension on the elastic presses the leg directly downwards without tending either to flex or to extend it.

Leather pads deaden the noise of the impact.

Extension is limited, as will be seen by comparing figures 58 and 59, by the vertical wooden rod meeting flat surfaces in the thigh and leg pieces simultaneously.

3. *Extending slings.*[1]—To the sling which passes over the shoulder on the side of the artificial limb, is attached a strap which passes down in front of the thigh piece and is attached to the upper third of the leg.

When the patient raises the leg from the ground, the weight of the appliance makes it slip down the stump, tension is thus produced upon this strap and as a result the knee is extended. By an adroit movement of the shoulder this extension can be carried out actively.

When the limb rests upon the ground the weight of the body presses the stump down into the bucket, the tension on the strap is released and consequently the knee is free to flex.

On pages 424 to 428 will be found figures showing the principal points in this extending brace.

The braces, whether they have or have not an extending strap, may be constructed in three ways:

a. To ease the constant pressure exerted on the

[1] This is an old French method used in Fouilloy's appliance, which has, however, only become generally used in the suspending braces of the American appliance.

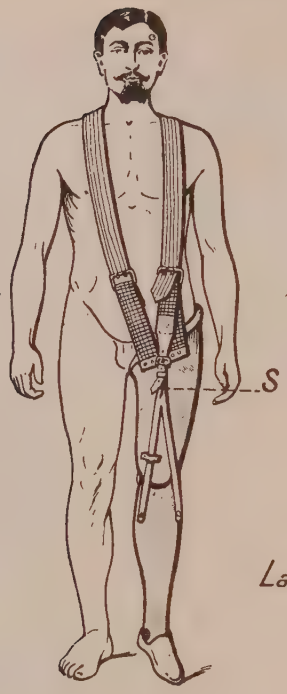


Fig. 60.

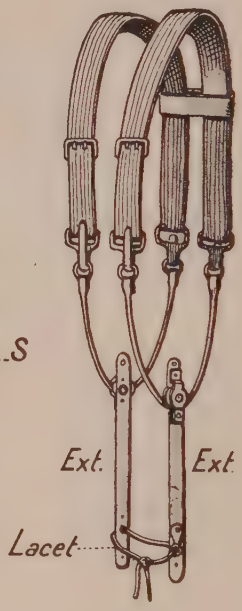


Fig. 61.

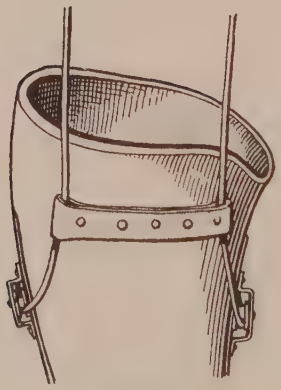


Fig. 62.

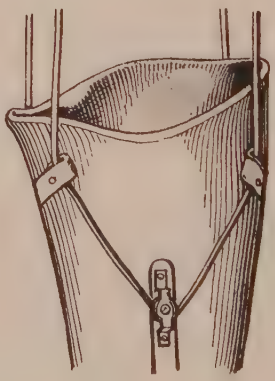


Fig. 63.

Fig. 60.—Fouilloy's Braces. Figs. 61 to 65.—Marks' braces. Fig. 61.—General construction of the braces. Figures 62 and 63.—Attachment at the sides of the thigh piece. Figures 64 and 65.—General view of the apparatus as worn.

shoulders by the strap which is stretched by the weight of the artificial limb, the brace may be made of elastic like the ordinary trousers brace. But the limb they carry is heavy, so they rapidly become overstretched and it is difficult to keep them properly adjusted.

b. The stretching is naturally diminished if the upper part of the brace is not elastic but an elastic section is inserted in its lower third, in front and behind.

c. But the patients almost always say that better command of the limb is obtained with inelastic braces. If the strap is wide on the shoulder, the pressure is well borne, and the lower attachment may be made narrower, consisting of a leather thong (Fig. 64).

To attach extension braces to the front of the leg piece the old and simple method adopted by Fouilloy may be used. It consists in attaching an elastic strap to the brace which passes over the shoulder on the side of the amputation (and which is fixed to the top of the thigh piece alongside of the other brace). The elastic strap ends in a bifurcated leather thong each branch of which (held in place by a loop of leather) descends obliquely alongside of the patella surface to be attached to the corresponding side of the leg in its upper third (Fig. 60).

In Marks' method the braces end below in loops made of a leather thong (Fig. 61). These are held against the thigh piece by passing under leather bands; they reach as far down as the upper third on the inner and outer sides of the thigh (Figs. 62 to 65).

To each of the loops, gliding on them by means of a pulley, is attached a leather strap which descends vertically to the upper third of the corresponding surface of the leg, being held in place by passing under

a leather band. These two straps are attached to each other in front by a lace, which draws them towards the middle line, and in this way brings their line of action forwards. The tighter the lace is drawn the more powerful will be the extending force.

Instead of attaching the extension brace to the

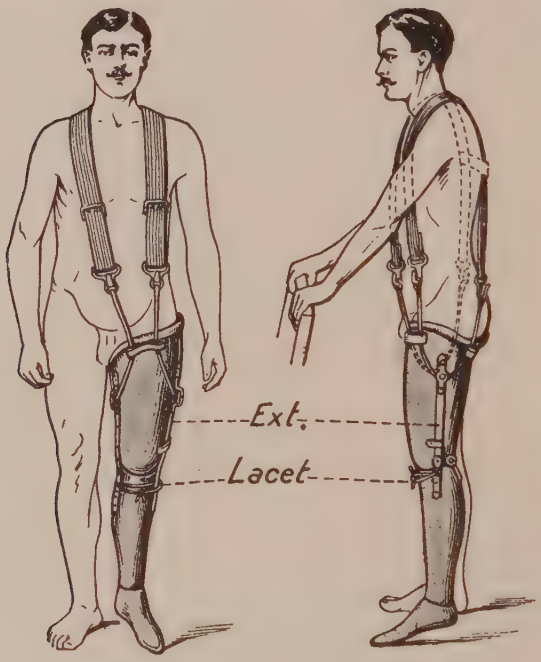


Fig. 64. Fig. 65.

leg piece it may be made to pass under a pulley in the interior of the knee. What actually happens is that the thigh piece drops, owing to its weight, when the limb is swung free; this throws a strain on the brace which is transmitted to the leg piece by the following mechanism. The metal stop described on page 419 which limits extension of the knee during the period of weight bearing, is prolonged upwards

and forwards beyond the hole through which the axis of the knee passes, this prolongation being furnished with two wooden pulleys (Fig. 69). The loops attached to the braces enter the front of the thigh piece, each by a separate opening, turn under the

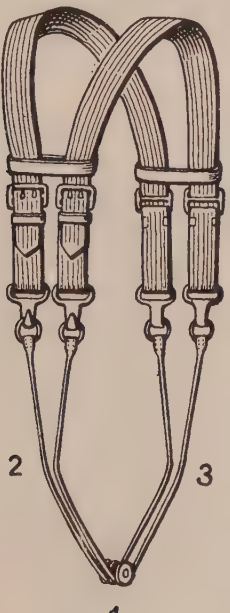


FIG. 66.

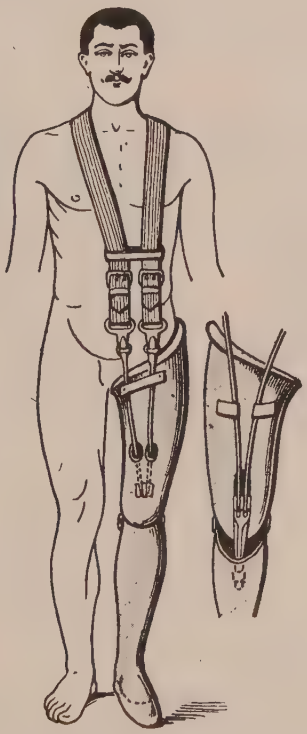


FIG. 67. FIG. 68.

corresponding pulley and emerge again posteriorly (Figs. 66 to 68).

This mode of attachment has the advantage that when the limb is swung the movement does not take place upon the shoulders—which easily become chafed by the ordinary suspenders—but upon the pulleys upon which the leather thongs work.

The mechanism shown in figures 69 to 71 is interesting. When the metal lever moves around the axis of the knee joint, its lower end and the pulleys at the upper end travel in opposite directions: in flexion the pulleys move downwards and forwards, the lower end upwards and backwards; in extension they move in the opposite direction. Therefore

Fig. 69.

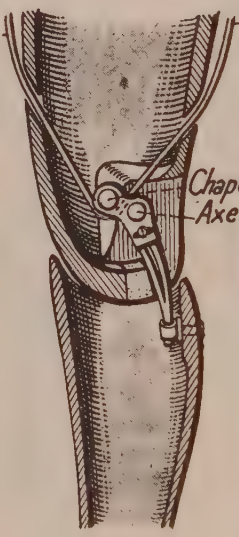


Fig. 70.

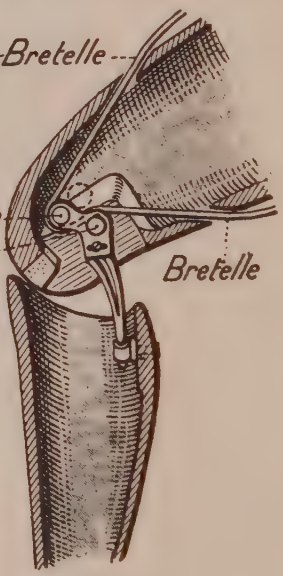


Fig. 71.

when the limb is swung and the knee bends (Fig. 71), the thigh piece drops of its own weight, the braces tighten, raise the pulley and consequently make the lower end of the lever move downwards and forwards, thus extending the knee joint.

D. *Mechanism to secure rigidity of the knee during weight bearing.*—During the time that the healthy limb is raised from the ground and carried forwards there must be complete rigidity of the artificial limb in the extended position. This is

secured by mounting the foot in the equinus position. When it has been swung forwards, in taking a step, the limb comes in contact with the ground heel first; then, as the leg becomes vertical the entire sole lies flat on the ground; if the foot is in equinus this position is only possible with the knee hyperextended, or with full extension it may be possible for a very

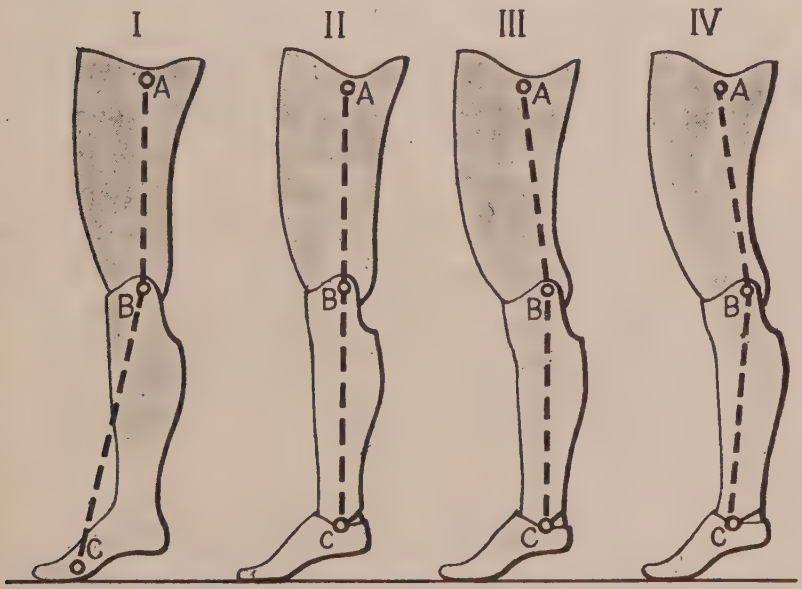


Fig. 72. Fig. 73. Fig. 74. Fig. 75.

In Figure 72 the foot is fixed, the weight comes upon the point of the foot, and pressure upon the axis AB tends to close the angle ABC, *i.e.* to produce a genu recurvatum, and so to lock the knee in extension. If the foot is articulated, equilibrium is secured in the same way. Figures 73 to 75 are intended to show that in order that the axis ABC may not be vertical (Fig. 73) the axis B of the knee must be behind the perineal concavity in the bucket, and it is better if at the same time the axis of the ankle joint C is carried forward.

short period. So that it is the weight of the body that locks the limb in the extended position, the sole of the foot sloping obliquely downwards and forwards; and the weight being taken on the toe. There is

always a tendency to hyperextension, and to avoid straining the limb in this direction (as occurs in a living knee which is forced into the position of genu recurvatum by a talipes equinus) it is as well, as we have already said, to oppose it by some passive resistance, either in the form of a simple popliteal check cord or by a stop fixed to the front of the leg.

This extension is unlocked automatically at the moment when the weight is thrown forward on the healthy limb, the artificial limb rising on its toe and the knee commencing to bend because the braces are relaxed.

E. *Movable ankle.*—We have taken as our type a limb with a fixed foot. There are, however, a number of methods of attaching a foot with a *movable ankle joint.* The general principles and the mechanism for securing stability are those which we have already studied, but the gait is more supple, at the price it is true of somewhat delicate articulations and therefore of simplicity.

The foot is made of a single piece of wood; it is divided transversely at the level of the middle of the metatarsal bones, and the anterior part (shaped like toes) is attached by two pieces of leather, dorsal and plantar, between which are two indiarubber cylinders which keep the toe piece extended 15° to 20° when at rest, and which allow, when the foot is pressed on the ground, an extension to 45°.

This foot is mounted on the leg at an angle of 45° beyond the right angle, with an interposed rubber cylinder, which allows of the diminution of the angle to 25° or 30° but no further. It is important that flexion to a right angle should not be possible. In fact, a slight degree of equinus is essential in order to secure

the locking of the knee in extension, exactly as with the fixed foot (compare figures 73, 74 and 75 with figure 72), and as on the shoe there is always a heel which makes us walk normally in slight equinus, the two feet will be similar in appearance, the slight movement of the artificial foot being sufficient to allow a rolling movement of the sole upon the ground (Figs. 77 to 86).

The figures 76 and 76A show the simplest and best known mechanism. On the upper surface of the foot two cavities are hollowed, one in front and one behind

FIG. 76.

FIG. 76A.

the bolt of the ankle joint, in each of these is placed a cylinder of rubber; the posterior cylinder is about twice as thick as the anterior. Above them the leg piece is fixed, it ends in front in a short instep which lies within the cavity hollowed out in the foot.

The foot is attached to the leg piece by a bolt made as follows: a steel tube fitting into two corresponding grooves in the leg and foot, is attached to the leg by being prolonged upward into a vertical rod, which is secured by a nut inside the leg piece.

Upon the steel tube moves a brass rod shaped like an inverted U, the two ends of which pass through the foot and fasten beneath it by two nuts (Fig. 82).

Raising the point of the foot further compresses

the anterior piece of rubber, lowering it relieves the pressure upon this piece and compresses the posterior piece. But the tension and the size of the pieces of rubber are such that they are under slight compression in the position of rest, the foot being in 30° of equinus. So that this foot is never loose. When pressure is made on the point of the foot it may come to within 15° or 20° of a right angle, but it returns to its angle of 30° as soon as the pressure ceases.

With boots on, with heels of 2·5 centimetres the

FIGS. 77 to 81.

Contact of the sole with the ground in normal walking. Heel first then toe, with progressive dorsi-flexion of the ankle joint. Compare with the contact of the artificial foot in figures 82 to 86.

two feet are in the same position when the soles are flat on the ground.

The forepart of the foot (representing the toes and the anterior part of the metatarsals) is kept in this position (Fig. 76) in slight extension by a piece of rubber, compression of which allows an increase of extension of 15° to 20°.

When a step is taken, the heel of the foot first meets the ground, the leg pointing downwards and forwards. Then the whole sole comes to lie flat on the ground, the degree of equinus being increased, the posterior rubber compressed and the anterior relaxed (Figs. 82 and 83), but when the limb is vertical the sole still being flat on the ground, compression of the posterior diminishes and that on the anterior increases

(Fig. 84). This remains unchanged up to the moment when the foot leaves the ground, whilst the heel rises and the weight is borne on the toe piece of the foot, which is forced into extension (Figs. 85 and 86).

This method of using rubber cylinders is the simplest. Another method, good but more delicate, is shown in figures 87 and 88. In the leg below the calf are two cross pieces of wood; the lower placed

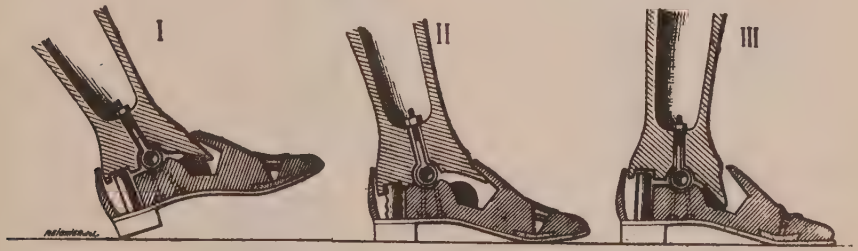


FIG. 82. FIG. 83. FIG. 84.

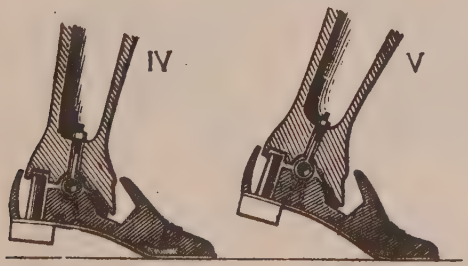


FIG. 85. FIG. 86.

transversely supports the upper which is antero-posterior and so increases its resistance to the cords which are attached to it.

The shape of these pieces of wood can be seen in the figures and require no further explanation. The bolt of the ankle joint is the same as in the foot last described. To the antero-posterior cross piece are attached two cords, which pass through the foot and are attached beneath it, one under the heel, and the

other about the level of the mid-tarsal joint. The posterior cord is inelastic and stops dorsiflexion of the foot. The anterior has a section of elastic in it; it prevents the dropping of the foot whilst the limb is being swung. A small pad of rubber placed in front beneath the anterior part of the leg piece allows, by

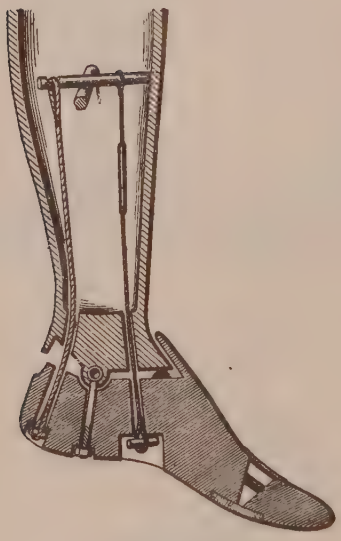


FIG. 87.

FIG. 88.

its compression, the partial correction of the equinus when the sole is pressed flat on the ground.

Some appliances allow the foot a little *lateral mobility*, by rotation around an antero-posterior axis, so that it may adapt itself to irregularities of the ground. We here illustrate the "Duplex foot," which is very ingenious but which has the defect that after a time the mechanism grates. The ankle attachment is carried out in the same way as in the limbs last described (in this particular limb it is

attached by cords), but the foot piece is divided as in a sub-astragaloid amputation; the lower surface of the astragaloid piece bears a median antero-posterior projection, tapering posteriorly and enlarged into a knob anteriorly, this lies in a corresponding groove in the heel piece; alongside this are two rubber

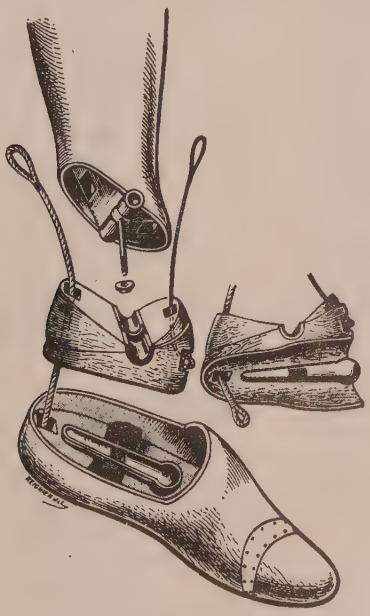


FIG. 89.—Duplex Foot.

cushions which are alternately compressed and relaxed as the foot inclines to one or other side.

Combined mechanism for knee and ankle joints.

This very ingenious combination, which, however, necessitates a rather complex mechanism, was devised by Palmer in 1850. It is carried out in the limb made by Frees, the mechanism of which will be seen to resemble that of the articulated foot shown on page 434 in figures 87 and 88.

Above the axis of the knee joint and at right angles to it is a wooden cross piece, to which are attached three cords, two behind the joint, one in front; these cords emerge from the thigh piece through an opening in its lower end (Figs. 90 to 92).

The posterior of these cords, made of hemp, ends inside the upper third of the leg. It limits the extension of the knee, exactly as described in the Marks leg.

The other two cords extend down to the foot, which is attached in a manner very similar to that shown on page 434, but with a single rubber cylinder behind, and with the instep cut obliquely so that when the joint is in the resting position of equinus there is an opening in front amounting to an angle of 15° to 20°. The posterior cord, of hemp, is attached in the heel; the anterior, made of catgut with an indiarubber section, enters the foot obliquely and is fixed a little in front of the middle of the sole.

When the knee flexes, the wooden cross piece tilts, its posterior end becoming lower, its anterior higher (Figs. 91 and 92), the elastic of the anterior cord is tightened, thus raising the front of the foot, whilst at the same time the heel cord is relaxed. Thus the mechanism which produces extension of the knee acts at the same time upon the foot; when the knee is straight the foot is plantar flexed to 20°, when the knee flexes the foot comes to a right angle. Thus the foot becomes dorsiflexed at the same time as the knee flexes, as in ordinary walking.

If the action in walking is watched, it will be seen that as the limb is swung forward, the toe is raised so as to clear the ground.[1]

[1] The mechanism of this artificial leg resembles that of the "tendon leg," which was in such common use in England before the present war that it is often called the English pattern.—(Ed.)

In the sitting position the anterior cord is not re-

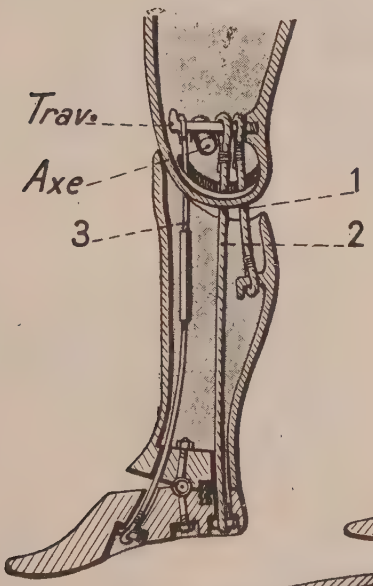


FIG. 90.

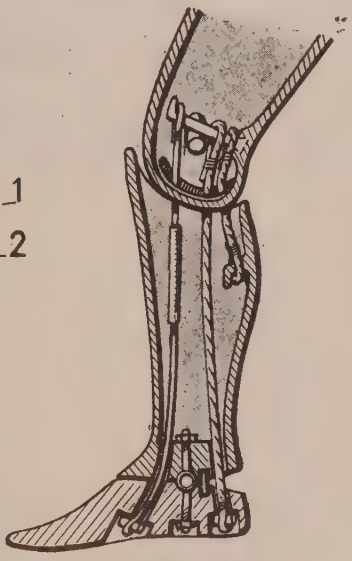


FIG. 91.

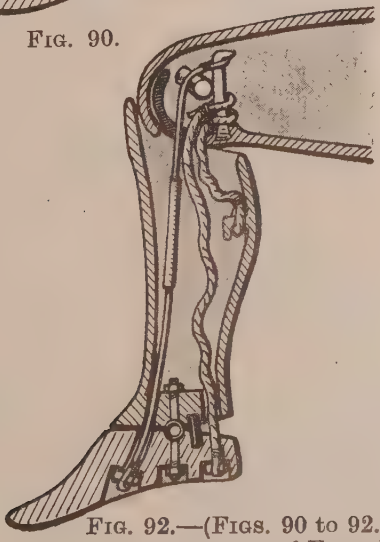
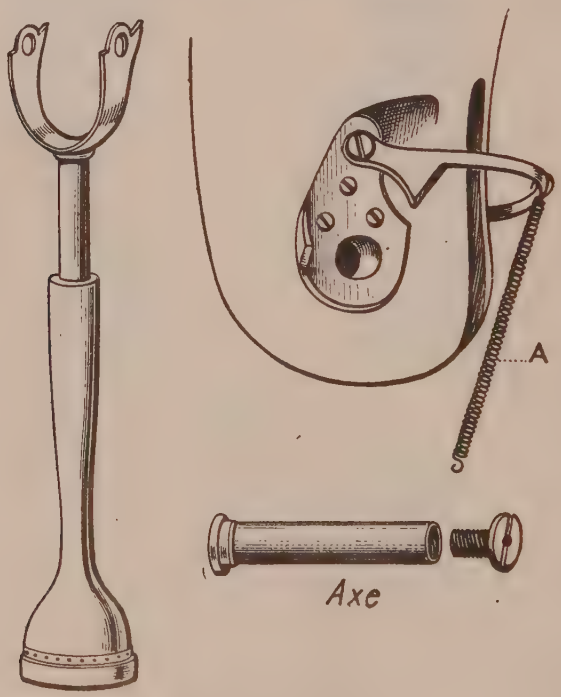


FIG. 92.—(FIGS. 90 to 92. Foot and Knee of Frees.)

laxed, there is no dead point, so that the knee always tends to extend. This is somewhat inconvenient.

Conversion of the articulated peg leg into the leg with free knee movement and vice versâ.

Whatever advantage it may be thought to possess, in our opinion the artificial leg with free knee joint



Figs. 93 to 95.

is only suitable for sedentary occupations; it is not suitable for manual labourers and particularly for agricultural labourers who are obliged to get about on rough ground. Hence it is not uncommon for a patient who has been provided with an American leg to come and ask for a peg leg. In figures 93 to 95 it will be seen that it is a simple matter to transform the limb into an articulated peg. It is only necessary

to attach the stirrup-shaped fork of the peg to the thigh piece by the knee bolt, and to add the double lock. To this peg may be added, if desired, the show calf and foot described on page 412 The full artificial leg can be rebuilt whenever it is wished.

On the other hand, an articulated wooden peg leg,

Fig. 96.

Fig. 97.

Fig. 98.

such as we have described under the name of the Federation leg, can be easily adapted for walking with a free knee. It is only necessary to unlock the knee joint and to add the artificial muscle or accumulator of elastic shown in figure 98. This supplies the extending force, the value of which we have shown on page 416. We consider that this appliance is excellent and we know patients who almost always

walk upon the peg, but who sometimes use a free knee for short walks. The conversion is simple and requires no special care. Under these conditions the fixed foot is almost always used ; there is nothing to prevent the fitting of an articulated foot, but we have already seen that there is no great difference in walking between the old-fashioned fixed foot of the Marks leg and the more or less complicated articulated feet of more recent design.

II. Limbs without bearing upon the Ischium

For amputations through the condyles of the femur, and similar amputations (disarticulation of the knee and very short stumps below the knee).

Certain orthopædists do not know how to fit an artificial limb to an amputation through the condyles of the femur; they come therefore to the conclusion that this is a bad operation, and ought to be replaced by an amputation above the condyles.

The two objections raised to this amputation are :—

1. That it is impossible to fit a wooden bucket because the bone at the lower end of the stump is larger than it is at a higher level.

2. That it does not leave enough room to fit an artificial knee joint at the right level.

These two objections are not valid, and, on the other hand, this amputation allows us to fit an artificial limb with complete end bearing, and this is a great advantage.

1. *Fitting of the bucket.*—The first difficulty is easily got over. All that is necessary is to cut away the front of the lower half of the bucket, and to cover in this opening with a lacing piece of leather. The

stump passes into the top of the bucket, comes out of this opening and then falls back into the enlarged lower end where it takes a direct bearing (Fig. 99).

2. *Level of the knee joint.*—It is clear that if the

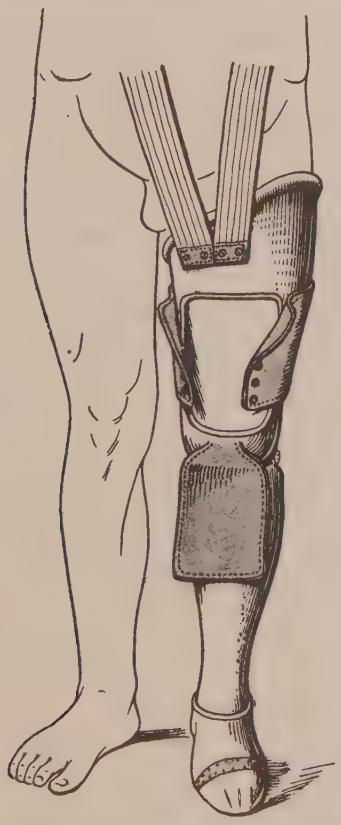


FIG. 99.—Limb with end bearing for amputation in the region of the condyles of the femur. Anterior part of the thigh bucket cut away to allow the insertion of the enlarged lower end of the stump.

stump is too long it is impossible to fit a knee joint with a bolt right through at the same level as the opposite knee. The thigh piece would have to be prolonged downwards in order to allow of the insertion of this bolt.

This arrangement would not affect walking, but would be unsightly in sitting because of the inequality in the length of the thighs.

It is easy to overcome the difficulty by attaching the leg by two independent lateral hinge joints, without a bolt right through, using the stirrup-shaped fork and the double lock, if a peg is used. This method, as we have already stated, is not so strong, but this is to a large extent compensated for by the possibility of getting a direct end bearing.

3. *Direct end bearing and suspension.*—If the stump is well covered with a good anterior flap and if the lower end of the bucket is accurately moulded upon it with an interposed layer of felt, the patient can walk directly upon the end of the stump, without it being necessary to carry the bucket up against the ischium, simple braces being used as the means of suspension.

4. There is nothing special about the braces or about the extending strap if the knee is free, nor about the method of attaching the foot.

These limbs for long stumps do not require any spring to extend the knee, if one is wanted an artificial muscle is quite easily fitted.

We have taken as our type an amputation through the femoral condyles.

The covering of the stump is excellent, and pressure is taken upon tissues which are naturally adapted to it (the thick skin and fibrous tissue over the patella), specially if it has been possible to keep the patella in the flap and fix it across the cut surface of the femur (Gritti's operation).

The mechanical points in the fitting of an artificial limb for an amputation through the knee joint are the same. But this amputation seems to us to be inferior

to that through the condyles. The sacrifice of three centimetres in length is of no importance in an appliance with direct end bearing ; and, on the other hand, disarticulation has several disadvantages :—

1. The enlargement of the femoral condyles, without any compensating advantage.

2. The bearing upon the two condyles, separated by a groove.

3. The insufficient covering of the condyles by the thin skin of the front of the leg.

The principles of fitting a limb are the same in amputations of the leg in which we are obliged to make the patient walk upon the bent knee (too short a stump, the position of the scars, persistent osteitis, the impossibility of straightening the knee when it is ankylosed or stiff in a flexed position), as in the old-fashioned kneeling pin leg.

A posterior transverse band, passing over the bent stump helps to hold the limb on.

CHAPTER IV

ARTIFICIAL LIMB FOR DISARTICULATION AT THE HIP JOINT

Attempts have been made to attach to the pelvis, by means of a waistbelt or braces, a wooden artificial limb whose upper end is fitted directly on to the tuberosity of the ischium. So far these have met with little success. In our opinion, the only really practical method is to enclose the whole stump and pelvis in a regular corset, and to attach the artificial limb to this corset.[1]

The moulding of this corset upon the stump must be accurate.

The tuberosity of the ischium is the only bony point in the stump upon which pressure can be taken. The corset may be made of leather, but, until a new order is issued, the material of choice is celluloid, moulded upon a plaster of Paris cast, in spite of the disadvantage mentioned on page 384.

The limb is an articulated peg leg, with convertible knee joint and double lock, exactly the same as in the limb for amputation through the thigh.

It is attached to the pelvis (*i.e.* to the tilting table), as shown in figures 100 and 101, by a joint with a double anterior lock, which allows the patient to sit down by flexing the hip.

[1] Amongst English limb makers this moulded corset with the steel hip attachments is usually known as the "tilting table."—(Ed.)

This general description and an examination of figures 100 and 101 will suffice to explain this appliance. It is comparatively rarely required, and its construction is difficult; we consider that the forms shown in

Fig. 100.

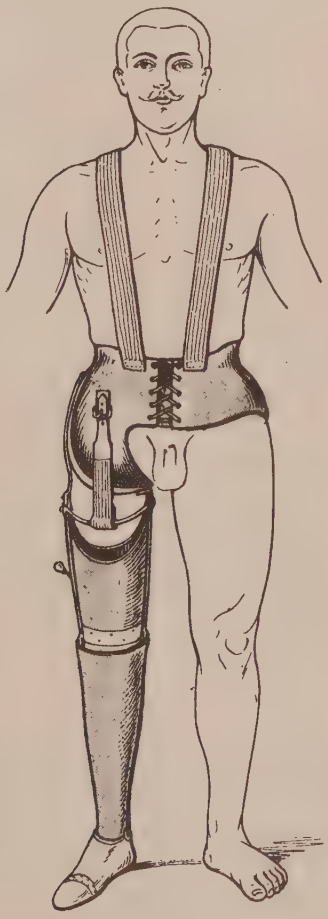


Fig. 101.

the illustrations are the best. It is only possible to fit such an appliance when the conditions are good, when the scar is above and in front of the ischium, and when the latter is well covered.

CHAPTER V

ARTIFICIAL LIMBS WITH FREE KNEE JOINT FOR AMPUTATION THROUGH THE LEG

If the leg stump is ten centimetres long, if the knee joint is freely mobile and capable of complete, or almost complete, active extension, and if there are no adherent scars around the tuberosities of the tibia, the American apparatus with free knee joint should be adopted.

Walking on the bent knee (as stated on page 443) with the "poor man's peg" may be allowed as a temporary measure, but the patient must be advised to give his knee a rest frequently in order to lessen the risk of stiffness in a flexed position.

There are two methods of fitting, corresponding with those we have described for the thigh.

1. For the ordinary amputations with bearing upon the top of the leg.

FIG. 102.—Limb fitted upon the patient. Note that he stands upon the toe, and that the knee is flexed.

FIG. 103.—Posterior view of the same limb.

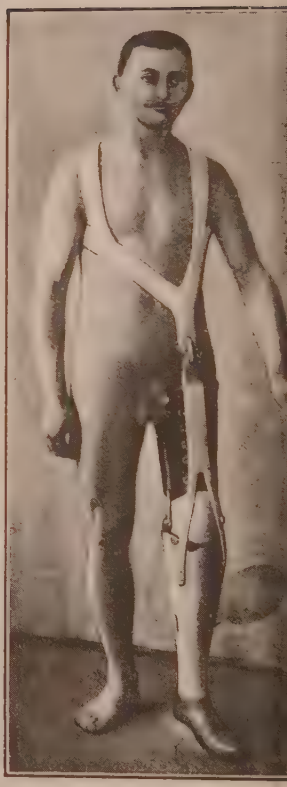


FIG. 104.—Anterior view of the same limb.

2. For amputation very low down with end bearing upon the extremity of the stump.

I. Appliances with Bearing upon the Tuberosities of the Tibia

An artificial limb for amputation through the leg with a free knee joint is composed of two parts : a leg piece (with foot) which is fitted to the bony prominences around the top of the stump and supports them ; and a suspensory apparatus which consists of a lacing thigh corset.

A. Leg Bucket.—The points on which the top of the bucket must be fitted are the internal tuberosity and the anterior tubercle of the tibia, and the head of the fibula, so that hollows corresponding to these must be carved out.

Pressure upon the head of the fibula is often painful, and a deep concavity is therefore carved out for it. The pressure then comes upon the external tuberosity of the tibia which, however, ordinarily bears little weight.

Whenever possible direct end bearing upon the termination of the stump should be used as an accessory to relieve the weight upon the tuberosities of the tibia ; this is obtained as described on p 387 It is only possible if the scar is lateral and if there is a good thick posterior or external flap (in the upper third of the leg). An anterior flap is the least satisfactory.

It is also advisable—

That the inner surface and the anterior border of the tibia be divided obliquely, and that the fibula be divided at a higher level than the tibia.

The fibula must not take weight, it is too slender. In high amputations it has a tendency to tilt outwards, causing the double inconvenience of widening the stump and of projecting through the skin. If only 4 or 5 cms. of the fibula remain it is perhaps best to disarticulate and remove it.

With a fitting arranged in this way, we consider that the convenience of walking with a free knee can be assured to patients whose stumps measure only 10 cms. from the lower border of the patella.

These principles can be applied to a limb constructed either of wood or of leather.

The leather appliance (French method) is formed of a leather cylinder, strengthened by two laternal steels which articulate at the level of the knee joint with two similar steels in the thigh corset. Its upper edge may be strengthened anteriorly by a metal plate, but in practice the latter cannot be made to fit with precision the bony prominences enumerated above. It is actually the edge of the leather, adjusted by lacing, which supports tibial tuberosities, and therefore the precision of the fit is soon lost.

For this reason, for amputation below the knee, the American method of construction with a wooden bucket is demonstrably superior.

These limbs are infinitely more durable than the French. They may last three years, whereas the French limb used by a young and active patient is worn out at the end of the first year, and it was for this reason that a limb with a free knee joint used to be considered a luxury.[1]

This wooden bucket is shaped very accurately to the bony prominences, and by passing the fingers over its inner surface the three hollows corresponding to the points of pressure enumerated above can be distinctly felt.

It is important to describe the shape of the upper edge of the bucket in order to guard against two points which may interfere with flexion—

I. Pinching of the tissues behind the knee.

II. The tendency of the stump, when it is short, to tilt forward in the bucket (Fig. 108).

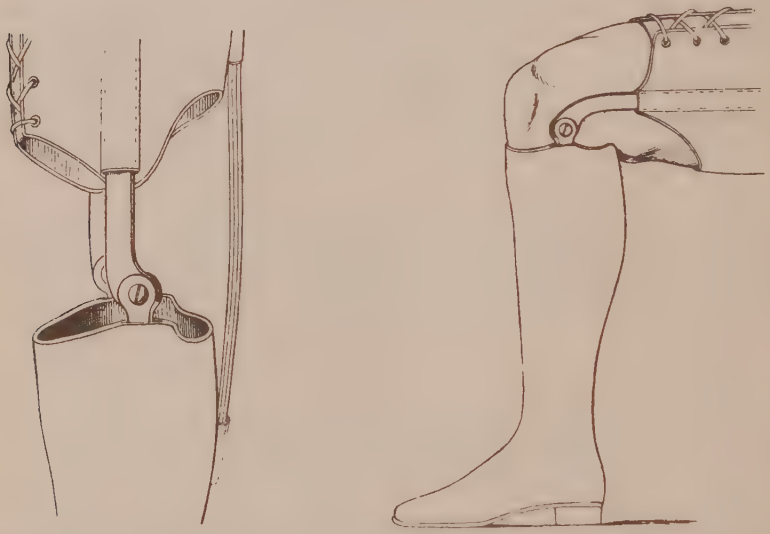
Pinching of the flesh behind the knee in flexion takes place between the edge of the leg piece and that of the thigh corset.

If the top of the bucket is horizontal, it must inevitably occur, even if the edge of the thigh corset is well cut away (Fig. 106).

It can be avoided by cutting away these two edges into concavities opposite each other.

[1] That is the reason that amputation at four fingers' breadth below the knee used to be called for the working class, amputation at "the seat of election," a name which is no longer applicable and which is liable to mislead the operator.

In the French limbs made of leather it is usual to make the leg piece very high in front, *i.e.* as high as the middle of the patella. This is quite useless. The posterior border is cut down to a depth of two fingers' breadth below the axis of the joint. Pinching is thus avoided, but the posterior support is insufficient,

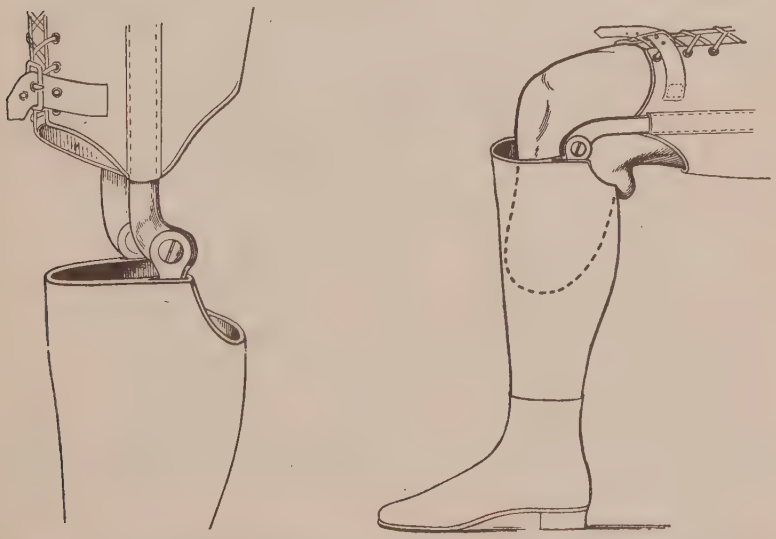


FIGS. 105 and 106.—Limb in which the upper edge of the leg bucket is almost horizontal; in the sitting position (Fig. 106) the flesh at the back of the thigh is pinched even if the lower end of the thigh corset is well cut away.

the stump tilts forward as described above and the bucket gapes in front (Fig. 108). If the top of the bucket is horizontal—as in certain American limbs—there is, as we have already said, pinching of the popliteal tissues and compression of the popliteal vessels and nerves (Fig. 106). A concavity is therefore necessary, but one reaching to one finger's breadth below the axis of the joint is sufficient. In front the

edge of the bucket reaches up to the joint line, this is quite sufficient to enclose the bony prominences (Fig. 109).

The posterior concavity of the leg piece is combined with a concavity in the thigh piece varied in accordance with the thickness of the popliteal soft parts.



FIGS. 107 and 108.—If the leg bucket is hollowed out too much at the back, the stump is tilted obliquely forward (Fig. 108), the knee loses contact with the bucket, and the flesh at the back of the thigh is pinched.

To diminish further the tendency of the stump to tilt forward the posterior edge of the bucket is flattened so that the shape of the top of the bucket is triangular with curved sides and angles much rounded (the anterior angle over the tuberosity of the tibia being obtuse). This is the natural shape of a section of the top of the calf. In this way the posterior muscles are flattened and no

longer tend to escape from the bucket when the knee is flexed. In figures **110** and 111 are shown

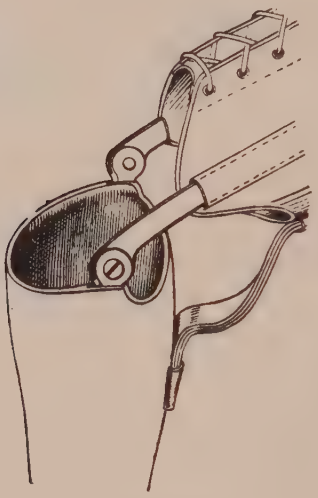


Fig. 109.

two ways in which this flattened posterior margin may be shaped.

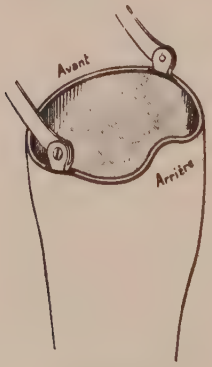


Fig. 110.

Fig. 111.

B. Suspension Apparatus.—The leg is attached (*a*) by a thigh corset taking its hold on the femoral condyles, and (*b*) by braces over the shoulders.

(*a*) *The thigh corset* is made of leather laced in front. Two lateral steels curving in sharply against the upper part of the condyles (Fig. 112) form the most effective part of the support. At their lower ends they are articulated with two steels passing up from the top of the leg to which they are attached. The joint (Fig. 113) is composed of a nut, A, into which fits a screw. Around the nut is a copper ring made

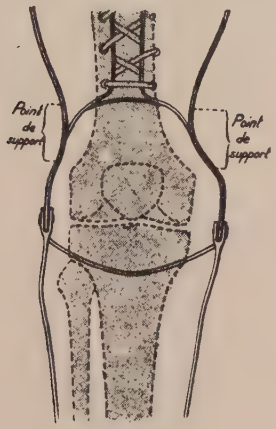


FIG. 112.

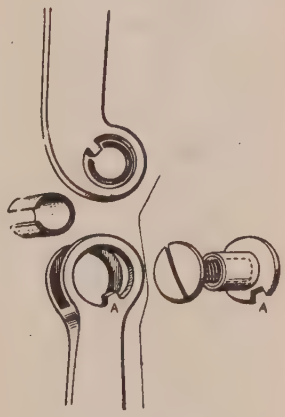


FIG. 113.

FIG. 112.—The thigh steels, curved in above the condyles, hold the limb on very securely.[1]

FIG. 113.—Details of the joint at the knee.

to move with the femoral steel by means of a stop-notch. When the knee flexes and extends the wear comes upon this copper ring. The steels remain intact. If the joint works loose it is sufficient to renew the ring.

(*b*) *The braces* are a very useful addition which French orthopadædists should employ systematically.

[1] In this illustration the joints are placed too low. They should be opposite the centre of rotation of the knee joint, *i.e.* a transverse line passing through the femoral condyles. (Ed.)

They increase the stability of the limb and allow the thigh piece to be laced less tightly, so that contraction of the thigh muscles is facilitated.

Support may be given by a strap from a waist-belt as shown in figure 117, but proper braces are better.

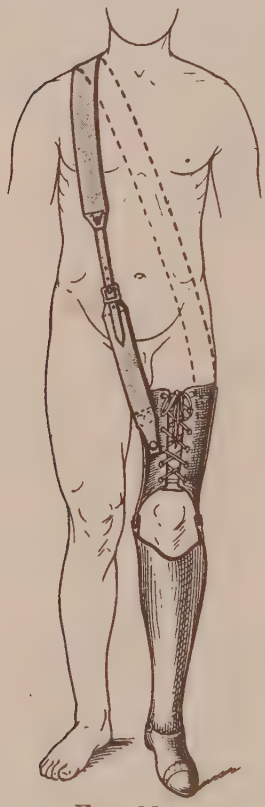


Fig. 114.

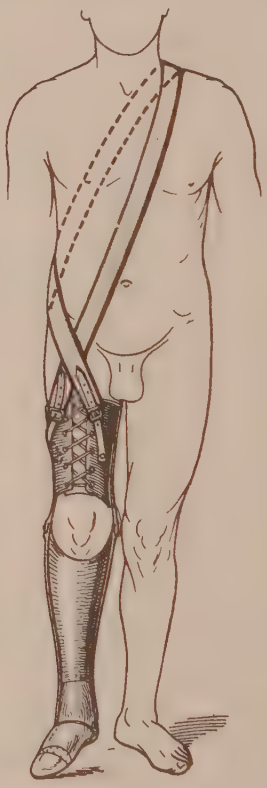


Fig. 115.

These braces pass over the shoulder of the sound side and are attached either to the thigh corset or to the leg piece of the artificial limb. Attachment to the thigh corset is made by a single strap either in front and behind (Fig. 114) or on either side of the front lacing, the ends of the strap crossing in

front of the groin (Fig. 115). It is a simple matter to add to the brace an extending strap, such as we have described for the artificial limb for amputation through the thigh (page 424). It is only necessary

Fig. 116.

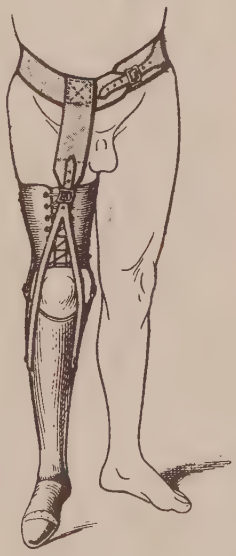


Fig. 117.

to terminate the brace in a strap from which two branches pass down in an inverted V and are fixed to the sides of the front of the leg piece (Figs. 116 and 117). This is unnecessary if the stump is long, for its leverage will then be good. It is, however, very useful for short stumps which give little power to

the action of the quadriceps. In the case of patients with a long stump an attempt has been made to abolish the thigh piece and suspend the limb exclusively by braces. This method, we believe, is inadequate even if it is completed by a transverse band above the knee (Figs. 118 and 119).

C. The Foot.—The foot, usually articulated, is fixed in exactly the same way as in a limb for an amputation through

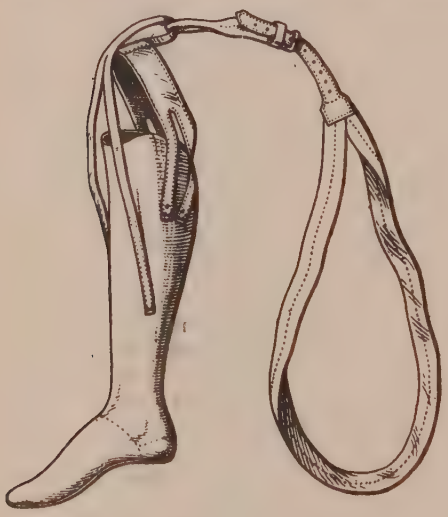


Fig. 118.

Fig. 119.

the thigh, *i.e.* it is mounted in the equinus position. But in this case, however, precautions must be taken against stretching of the posterior ligaments of the knee joint, because the equinus mechanically produces hyperextension of the knee, and a genu recurvatum may result. For this reason a strap must be fixed posteriorly between the thigh corset and the leg

piece to prevent full extension of the knee (popliteal check cord). This means that we make the patient stand and walk with slight flexion of the knee and with a corresponding elevation of the heel of the shoe (2–3 centimetres).

II. Appliances with End Bearing only

These appliances are suitable for certain amputations very low down in the leg which we must first define.

The orthopædist should consider the following operations as very low amputations of the leg, allowing of walking with end bearing only, and suitable for the same type of appliance :—

Supra-malleolar amputation.[1]

Disarticulation at the ankle joint.

Sub-astragaloid amputation.

Osteoplastic amputations through the os calcis

[1] In England, of course, this is always called Syme's amputation. It constitues the type *par excellence* of the end-bearing stump. Upon a good Syme stump a patient may be able to walk ten miles without an artificial foot, wearing simply an "elephant boot." Amputations above the Syme level are not end bearing, however long the stump may be. The other amputations in this region seen in English war surgery are the various types of osteoplastic amputations in which a part of the os calcis is retained (Pirogoff's amputation, etc.). These have the following defects :—

(1) There is often sepsis between the tibia and the os calcis, necessitating re-amputation. Osteoplastic amputations are unsuitable for septic surgery.

(2) Ankylosis between the os calcis and the tibia is often imperfect so that the bulbous end of the stump is unstable.

(3) The stump is too long to allow of the fixation of a good artificial ankle joint beneath it. A Syme's amputation leaves two to two and a half inches clearance between it and the ground.

I have not yet seen a sub-astragaloid amputation in war surgery, and only once a disarticulation through the ankle joint, the latter could not bear pressure and it was necessary to convert it into a Syme's amputation. In fact, in this region there is Syme's amputation and a number of other far inferior amputations which should never be considered when a Syme's amputation is possible. (Ed.)

(or amputation in which the os calcis is retained entire after removal of the astragalus).

Certain limb makers consider these operations are bad for the same two reasons that we have already refuted in connection with amputation through the condyles of the femur, viz.—

(1) The stump being enlarged at its lower end will not fit into a wooden bucket.

(2) The stump is too long to allow an artificial foot to be fixed below it.

From this it simply follows: 1. That complete enclosure of the stump in a wooden bucket is impossible; 2. That pressure must be placed directly and exclusively upon the end of the stump.

The latter condition is only possible if the state of the soft parts allows the cutting of a thick plantar flap to cover the cut surface of the bone and if care be taken to resect the posterior tibial nerve in the flap.

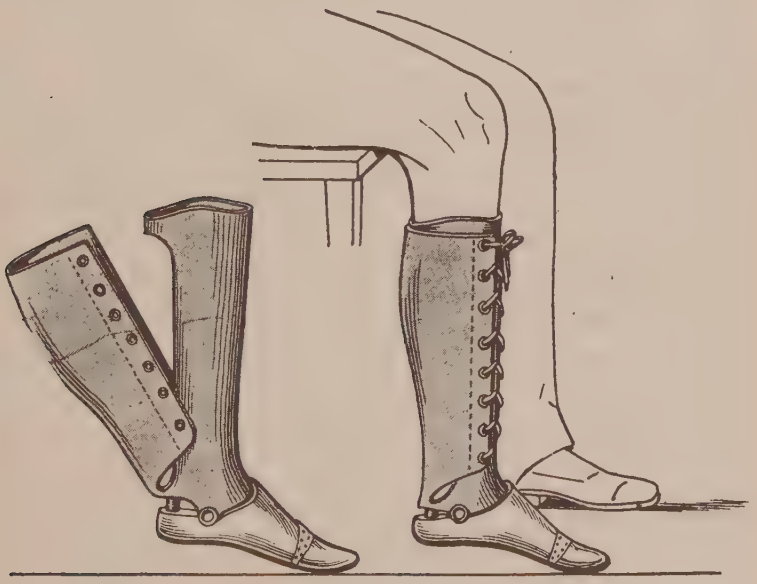
We therefore draw special attention to the excellent elliptical supra-malleolar amputation with posterior flap (Guyon's method) in which it is sufficient to retain a bare finger's breadth of skin from the plantar surface in front of the point of the heel. It bears direct pressure well, perfectly if a layer of the os calcis is cut with the scissors from the area adjacent to the tendo-Achillis and applied under the cut end of the tibia.

For all these amputations the anterior flap is bad. The thin dorsal skin of the foot is incapable of withstanding the direct pressure which is indispensable for this method of fitting.

Even if it were true that under these long stumps it is impossible to insert an artificial foot for lack of space, the operations which we have enumerated

above should be recommended if the flap can be cut in the way we have indicated.

Their great advantage—and the reason for retaining as much length of bone as possible—is that they allow walking directly on the stump without an apparatus. It is sufficient to have a circular shoe made by any shoemaker consisting of a heel more or less thickened



FIGS. 120 and 121.

surmounted by a lacing gaiter reaching halfway up the leg. Guyon's amputation constitutes the limit up to which this "elephant boot" is possible.

It is an unsightly apparatus, but its simplicity and cheapness should be taken into consideration, for it is quite possible that a manual labourer, especially a countryman, to whom an artificial foot and an "elephant boot" are given, will reserve the former for Sunday and use the other for his daily work.

Appliances with Artificial Foot.—The wooden piece which partly encloses the stump consists of a block carved to the shape of the stump and padded with felt, it is prolonged in front by an instep reaching to the level of the middle of the metatarsus, and above by a grooved piece which reaches halfway up the leg and encloses the anterior half of the latter. A leather gaiter is fixed at the sides and back and extends up the leg, being laced in front over the wooden piece as a field boot is laced over the leather tongue. The foot may be mounted at right angles to the leg, but it is better mounted slightly in equinus.

The sole and toes are of rubber as described on page 415

In studying figures 120 and 121 the following should be noted :—

1. The shape of the leg bucket in which an aperture behind permits the introduction of the stump which is enlarged at its lower end.

2. The mechanism by which the posterior gaiter laced in front fixes this leg bucket.

3. The articulation of the foot on a transverse axis.

CHAPTER VI

PARTIAL AMPUTATIONS OF THE FOOT

THIS name should be applied to amputations in which the mobility of the ankle joint is retained, *i.e.* Chopart's amputation (midtarsal disarticulation), Lisfranc's amputation (tarso metatarsal disarticulation), amputation of several toes with their metatarsal bones, or amputation of all five toes.

1. *The amputations of Chopart and Lisfranc.*— Chopart's amputation has a grave defect : the anterior muscles have not sufficient leverage to oppose this gastrocnemius and soleus, and the posterior tarsal bones tilt forward so that the patient walks, not on the lower surface of the os calcis and the plantar skin, but on the head of the astragalus and of the os calcis and on a painful cicatrix. If certain precautions are taken (careful preservation of the fibrous plantar flap and suture to it of the anterior tendons) this defect is not invariably present, and it is an exaggeration to say that Chopart's amputation " has never given anything but disappointment." It should, however, only be practised if the technique is well understood, and even then it is rarely indicated, because it demands almost as much plantar skin as Lisfranc's amputation.

Nevertheless I have seen some good Chopart

stumps the result of operations by myself or by other surgeons; they should be fitted like the stumps resulting from Lisfranc's operation.

With regard to the latter, they can be easily and comfortably fitted, provided that the scar is dorsal and is not stretched over prominent bones.

If the first cuneiform is not well covered it can simply be removed, no functional disability results. It is mainly upon the plantar surface of the stump that pressure is borne, but pressure comes also upon the anterior surface when the foot is tilted downwards.

FIG. 122.

The fore part of the foot which constitutes the prosthetic apparatus consists of a block of wood, which reaches forward as far as the middle of the metatarsus and ends in a vertical plate in front of the stump. This block of wood is carved to the shape of the stump and lined with felt. It is attached to the leg by a leather gaiter which laces in front.

Anteriorly it is prolonged into an artificial toe piece similar to that already described for the artificial limb for amputation through the thigh.

This appliance is not indispensable. It is sufficient to use a piece of cork shaped to the anterior surface of the stump and filling up the anterior part of the boot, its advantage, however, is that once the patient is fitted with this appliance he can wear an ordinary boot.

2. *Partial Amputation of the Fore Part of the Foot.*—These are—

Transverse amputation through the metatarsal bones.

Disarticulation of one or more toes with their metatarsal bones.

Disarticulation of one or more toes.

For any of these amputations all that is required is an ordinary boot, fitted with a cork, which is shaped to fit the stump and which fills up the space left by the amputation.

In order that the patient may walk well the scar should be dorsal and should not be tense.

We consider that the difficulty of maintaining equilibrium after removal of the head of the first metatarsal, or even of the whole of this metatarsal bone, has been much exaggerated.

Removal of a marginal metatarsal bone (either alone or with its neighbour), tends to make the foot tilt into varus or valgus; so that the boot needs to be stiffened and the sole thickened to avoid this.

CHAPTER VII

ARTIFICIAL LIMBS FOR AMPUTATION THROUGH THE FOREARM

THE constituent parts of an artificial arm are the same in principle as for those of an artificial leg, they are—

1. A means of attachment preventing the appliance from dropping as the result of its weight.

2. A socket, fitted to the stump and articulated with the last named at the elbow.

3. The terminal appliance, intended to replace as far as possible the amputated hand and, if possible, resembling it in appearance. In the case of the upper limb the advantages that wood possesses in giving strength and accuracy of fit do not apply, and the arm and the forearm pieces are made of leather, with lateral steels articulated at the elbow: this joint is active in the case of amputations of the forearm but purely passive in amputations of the arm.

We will commence by describing the appliance for amputation through the forearm, taking as our type amputation in the lower half. This will furnish an example which illustrates all the principles that should guide us, the ends we should have in view, and the means by which we can attain them.

When once we have studied the apparatus by

means of which the functions of the hand can as far as possible be replaced, a short description will suffice to explain what can be done when the loss of movement of the elbow and then a shorter and shorter stump in the upper arm oblige us to diminish the utility of the appliance.

We must study in turn: (1) The attachment of the upper arm socket; (2) the joint between this and the forearm socket; and (3) the appliances attached to the extremity of the forearm whether these take the shape of a hand or not.

1. Points of Attachment

1. Suspension.—In the exceptional amputation very low down, in which the roots of the thenar and hyperthenar eminences remain, the enlargement thus formed at the extremity of the forearm may be used for the attachment of a wristlet which may suffice to support the artificial appliance, provided that the latter is not intended for heavy work. In the latter case an attachment from the elbow at least must be added.

This method would evidently be out of the question in the usual class of case, viz. ordinary amputations through the forearm.

In these the attachment may be made in two ways:—

(1) To the humerus above the condylar enlargements, the epicondyle and the epitrochlea, the latter being much the more prominent.

(2) To the top of the shoulder, *i.e.* to the surface over the acromion and clavicle.

A. *Attachment to the Elbow.*—The simplest method

of attachment is that in which pressure is exerted upon the condyles of the humerus (Fig. 124). A leather armlet laced in front is furnished with two lateral steels, curved in above the condyles and articulated at the level of the centre of rotation of

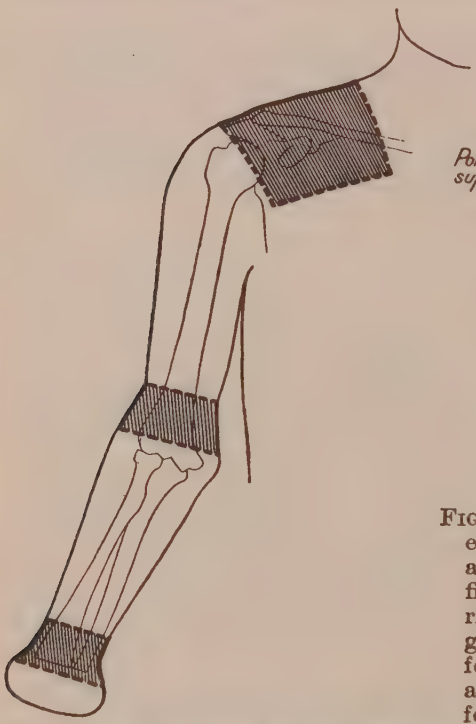


Fig. 123.—The three regions used as points of support, the shoulder, the elbow and the wrist.

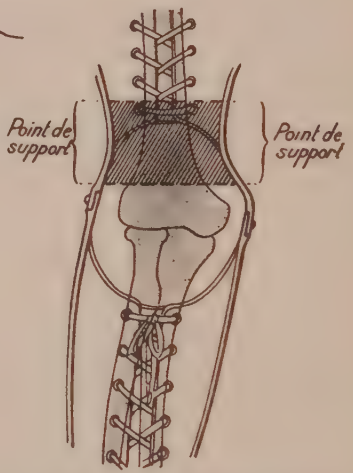


Fig. 124.—Suspension from the elbow. The side steels of the arm piece are curved in to fit upon the supra-condylar ridges of the humerus. A good method of suspension for long stumps, when the appliance is not to be used for heavy work. It should be supplemented in other cases by direct suspension from the shoulder.

the elbow joint with two similar steels in the forearm piece (the socket).

This direct method of attachment is sufficient for a low amputation, in cases where the patient does not do hard work. But if the stump is short and if the patient has to carry fairly heavy weights the appliance is only prevented from slipping by a consider-

able constriction of the arm, which results in a serious interference with muscular action.

B. *Attachment to the Shoulder.*—For this reason it is usually advisable to supplement this by an indirect attachment to the acromion and clavicle by means of a shoulder cap.

The firmest and strongest pattern consists of a piece of blocked leather, moulded to the shoulder,

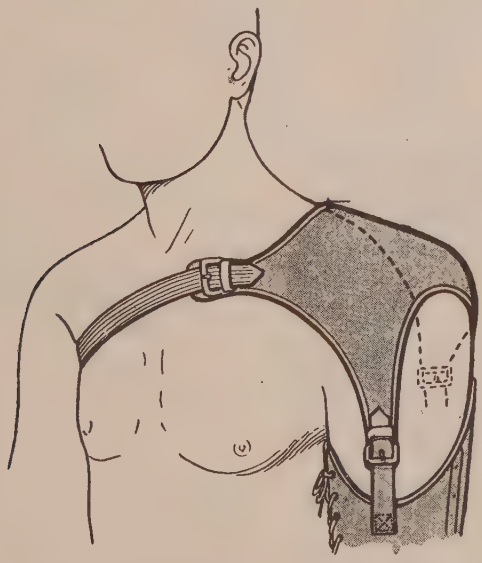
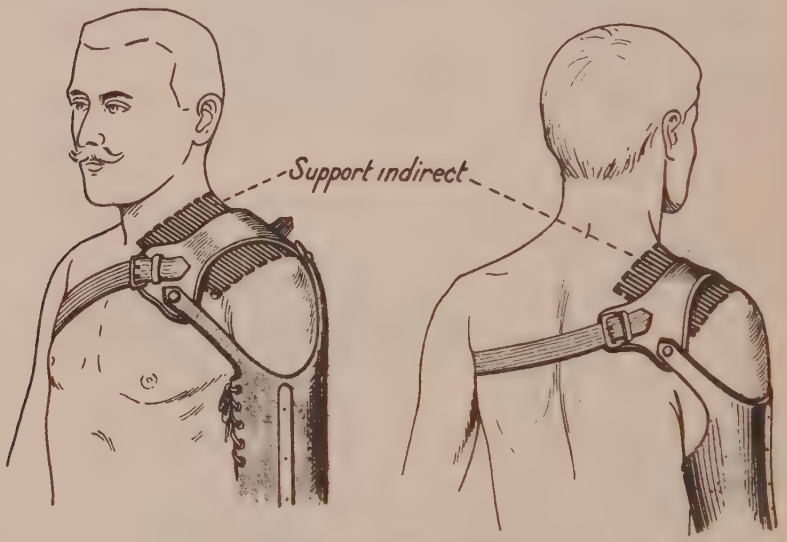


FIG. 125.

including the pectoral, supra-clavicular and scapular regions. This is kept in place by a strap which passes under the opposite axilla. It is cut away on the outer side of the acromion, the anterior and posterior borders being continued downwards on either side of the deltoid as two tapering straps to which the armlet is attached. In this way full liberty of movement is allowed to the shoulder (Fig. 125).

This pattern is strong, but cumbersome and heavy. It can be lightened by reducing it to an antero-posterior strap, 6 or 7 centimetres wide, over the clavicle and spine of the scapula, ending in front and behind at the level of the axillary folds in triangular enlargements. In the upper and inner angles of these



FIGS. 126 and 127.

are attached the ends of the axillary strap, to the lower and outer angles, prolongations from the armlet (Figs. 126 and 127).

The lightest method, but obviously also the least secure, consists in suspending the armlet by two straps, anterior and posterior, which cross above the clavicle and then pass in the form of a loop under the opposite axilla (Fig. 128).

The choice between these three methods of attachment depends upon the profession of the patient and the strength required by it.

2. Resistance to Upward Pressure.—The artificial limb should be capable of resisting upward pressure, when a thrusting force is exerted by the hand. This is secured in the following three ways, the hand being presumed to hang vertically with the elbow straight :—

(1) By pressure of the end of the stump in the socket (in amputations low down with a palmar flap—for example, in disarticulation at the wrist joint).

(2) By pressure of the top of the forearm socket on the enlargement of the forearm below the elbow.

(3) By pressure of the inner side of the upper edge of the armlet against the axilla.

But, in actual work, thrusting movements are nearly always made with the elbow bent to a right angle or almost so, then the pressure transmitted through the forearm piece is borne almost entirely by the steels of the armlet.

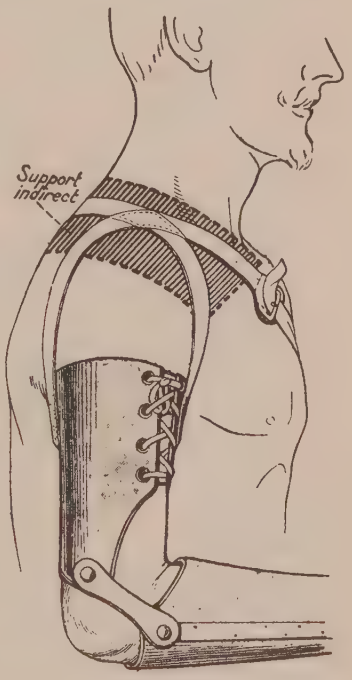


Fig. 128.

3. Resistance to Rotation.—A well-adjusted artificial arm cannot rotate on the limb because—

(1) The forearm is elliptical in section and not circular, this is specially so in the lower third.

(2) Flexion of the elbow is only possible if the artificial joint is in the same plane as the axis of the elbow joint—that is, the sagittal plane.

(3) The axillary strap of the shoulder attachment prevents rotation.

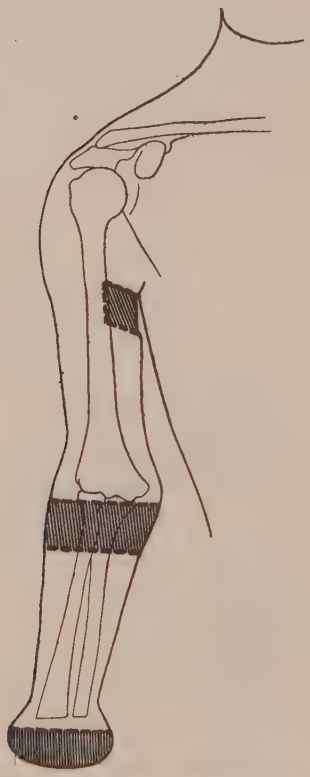


FIG. 129.—The three regions used as points of resistance to upward pressure.

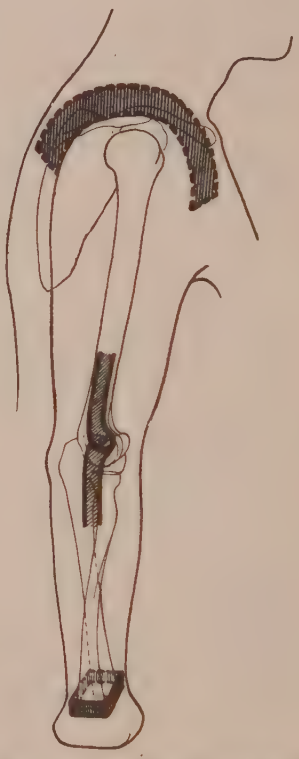


FIG. 130.—The three regions at which rotation of the apparatus may be prevented.

2. ELBOW JOINT

1. *The Concavity of the Armlet.*—At the elbow joint the pinching of the anterior soft parts on flexion is liable to take place in just the same way as occurs at the back of the knee in amputations through the leg. To avoid this it is necessary—

(1) That the axis of the joint should lie in a

prolongation of a line passing through the epicondyle and the epitrochlea.

(2) That the armlet and the forearm socket should be cut away in front in crescent-shaped concavities.

The depth of these concavities is estimated when the limb is fitted. Both the arm and the forearm may be cut away freely without any resulting inconvenience, provided that the stump is long; but if the stump is

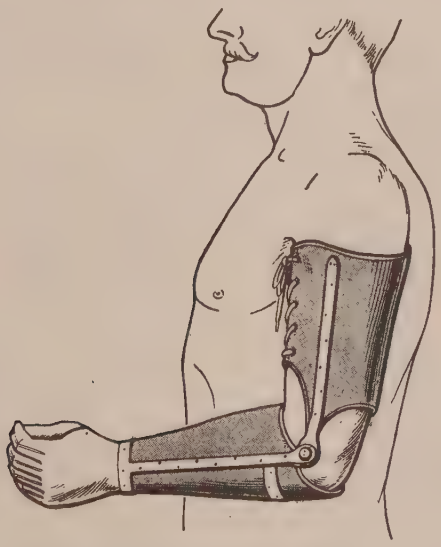


FIG. 131.—Limb for amputation in the middle third of the forearm.

short and includes only the upper third of the forearm, it is impossible to cut away the forearm socket sufficiently without depriving the stump of a proper hold in the socket, so that movements are not transmitted to the forearm lever with their proper force. Consequently the socket for the forearm must be cut away very little, and must be carried up to the level of the fold of the elbow when the joint is flexed. The flesh in front of the elbow will not be pinched if, the

forearm being fitted very accurately, the muscles of the upper arm are allowed free play, by cutting away the front of the armlet to half its height, but in this

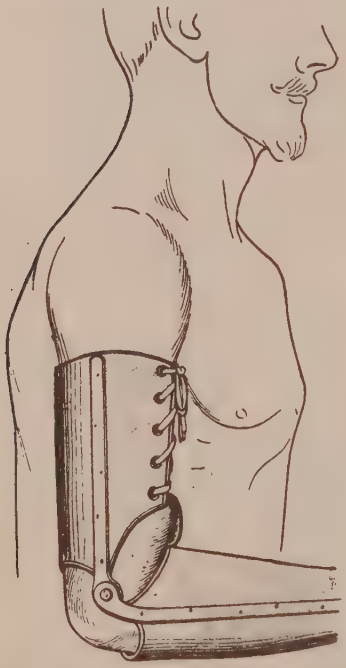


FIG. 132.—Bad apparatus for amputation in the upper third of the forearm. The front of the arm piece is insufficiently cut away.

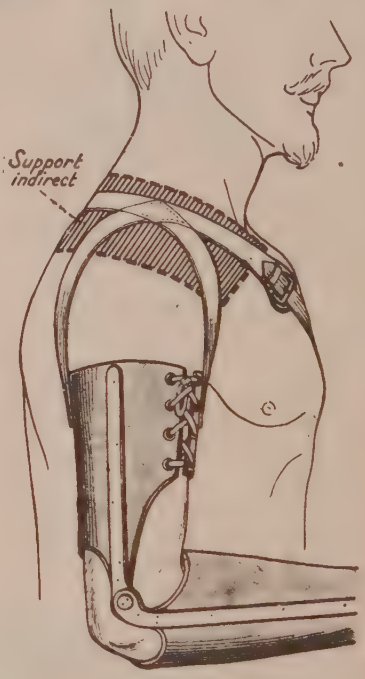


FIG. 133.—Good apparatus. The arm piece is well cut away, consequently the flesh does not bulge out.

case an indirect attachment to the shoulder is essential.[1]

[1] Another difficulty in fitting a short forearm stump arises from the fact that the antero-posterior diameter of the forearm immediately below the elbow increases considerably when the joint is flexed, because of the contraction of the muscles arising from the condyles. If the forearm socket is made to fit closely when the elbow is extended it will be too small when the joint is flexed and will prevent full flexion. If it was made to fit with the elbow flexed, there is risk of the stump slipping out of the socket when the joint is extended. (Ed.)

2. *Construction of the Joint.*—In most cases this is a simple articulation between the steels of the arm and the forearm pieces by two hinge joints.

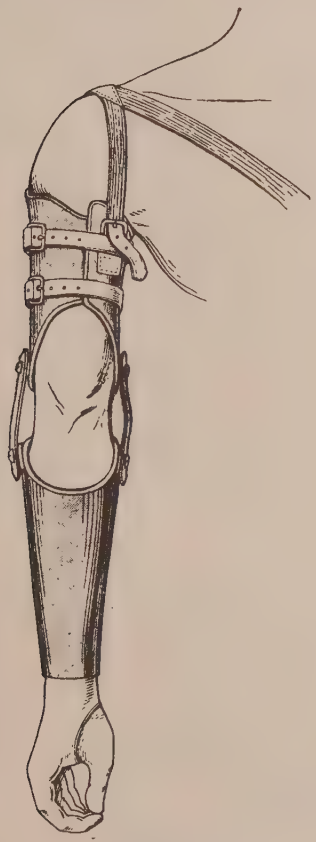


FIG. 134.

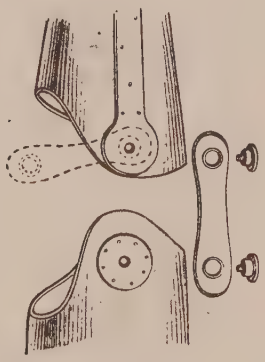


FIG. 135.

FIG. 134.—Limb for amputation through the lower third of the forearm, with elbow joint of strong leather.
FIG. 135.—Details of the joint.

The objection to this is that the movements of pronation and supination, if these are present in the stump, are abolished.

(*a*) *Long Stump.*—When the stump is long (amputation in the lower quarter) the following may be

Figs. 136 and 137.—Amputation through the forearm above the upper third. The elbow joint does not flex beyond the right angle.

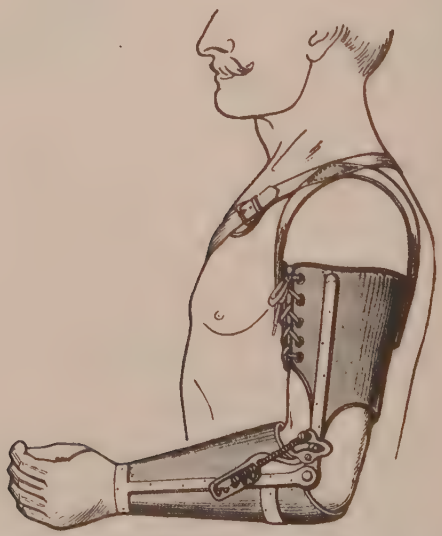


Fig. 138.—Limb for amputation through the upper third of the forearm. (For a description of the ratchet see page 515.)

used: The steels of the forearm socket are attached to the armlet, which is not furnished with steels, by two straight strips of hard leather jointed at each end with rivets to the corresponding piece of the limb. This allows a certain amount of torsion so that pronation and supination are to some extent possible. It is necessary to add an indirect attachment to the shoulder. Not only must the armlet, not being closely moulded over the condyles, be even when new laced so tightly as to be unbearable, but in addition the inevitable loss of shape of the unsupported leather will in every case soon interfere with proper support direct from the armlet (Figs. 134 and 135).

This method is, moreover, scarcely applicable to patients who will have to carry out heavy work.

(*b*) *Short Stump.*—The stump of an amputation in the upper third of the forearm is too short to be securely held in the forearm bucket. There is consequently a loss of power in the movements communicated, particularly in flexion, the arm of the lever being too short; in addition, the elbow joint in these cases is often a little stiff, so that flexion beyond a right angle is impossible (Figs. 136 to 138).

The chief functional difficulty depends upon the fact that, with the elbow at a right angle, the anterior surface of the forearm stump is too short to support a weight; for example, a basket held by the handle. The stump escapes partly from the bucket when the forearm extends. It is therefore well in such cases to fix the elbow at a right angle by means of a ratchet identical with that used in the artificial arm for amputation above the elbow (Fig. 138).

3. The Artificial Hand and Appliances

At the extremity of their forearm almost all patients wish in the first place to wear something that is shaped like a hand. Many people—and even many medical men—consider that this "artificial hand" is really useful. In actual fact, by means of fairly simple contrivances, it can be used to enable the patient to eat, to write, to put on and take off his hat, but it is out of the question for it to do real work. For that an appliance, a tool in fact, adapted for use and not for appearance is necessary.

The limb, therefore, will, as a rule, end in a hand, but for workmen this hand will be capable of being unscrewed and replaced easily by one or more appliances.

Attempts have been made to construct so called universal hands and forceps which will serve for any sort of work, but up to the present none of these inventions have given satisfaction. And the practical solution of the problem in the present state of affairs consists in devising a special appliance for a particular trade, studying carefully the movements necessary in this trade.

A workman who in the course of his occupation carries out a number of different movements may thus have several appliances, which he selects as he requires them. For example, a locksmith must be able to hammer, to file, and to drill holes in succession.

We will describe first the hand properly so called, then the appliances. The former is suitable for clerks, and it is for them that the various improved patterns that we shall describe are made. The latter are suitable for manual workers to whom should be given

a hand in which the mechanism is reduced to a spring thumb grip and one or more special appliances.

These appliances will almost always be constructed to carry out the movements made by the left hand in the course of the work, because the first step in the re-education of a patient who has lost the right hand should always consist in training the remaining left hand to carry out the work hitherto entrusted to the missing right hand.

A.—The Artificial Hand.

The hand, which is screwed into the end of the forearm socket in such a way that it is in semipronation when the arm hangs vertical, is nearly always made of wood, but occasionally of aluminium.[1]

It may be a simple show hand without any joint. This pattern is no longer used. It may be jointed in one or in several fingers. We shall first consider certain principles of construction which we can explain by describing the chief mechanisms used.

Simple Spring Grip Thumb.—The simplest and most useful articulation is that of the thumb, which when at rest is kept by means of a spring in the flexed position, with the grip against the index finger which is partly flexed (as are also the other fingers).

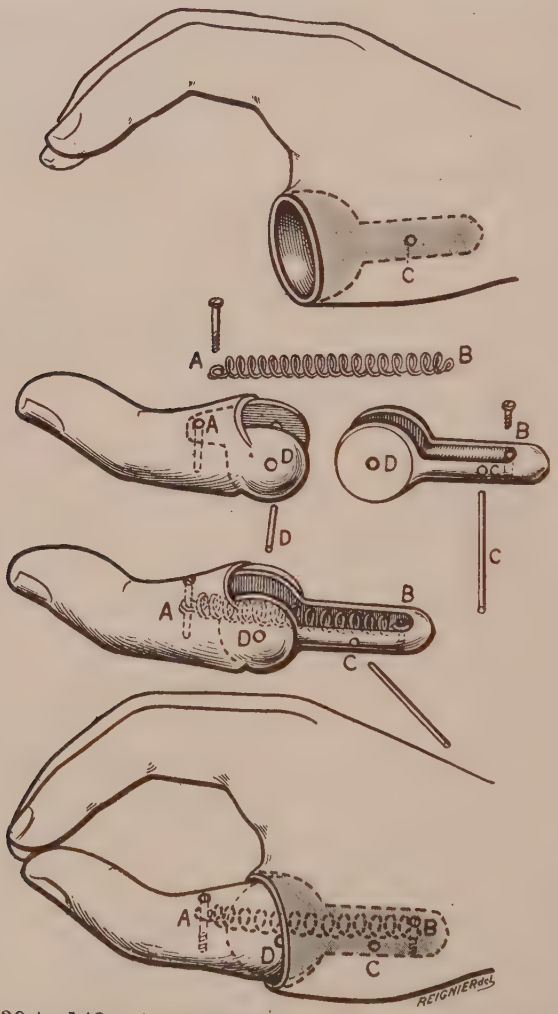
In many cases the patient is content with this simple mechanism. He opens the spring with the

[1] Hands are nearly always made of lime wood, which has the advantage of lightness, but the fingers are fragile and easily break. Instead of using hornbeam, which is hard but heavy, as the fragility only affects the fingers, some makers have overcome this difficulty by reinforcing the fingers by what they call a "philippeau."

The finger is divided throughout its whole length by a mortise 1·5 millimetres in width, in which are glued two layers of veneering wood (mahogany, rosewood, etc., extremely hard woods, or else a layer of hornbeam).

other hand and allows it to close on the object he wishes to grip (Figs. 139–145).

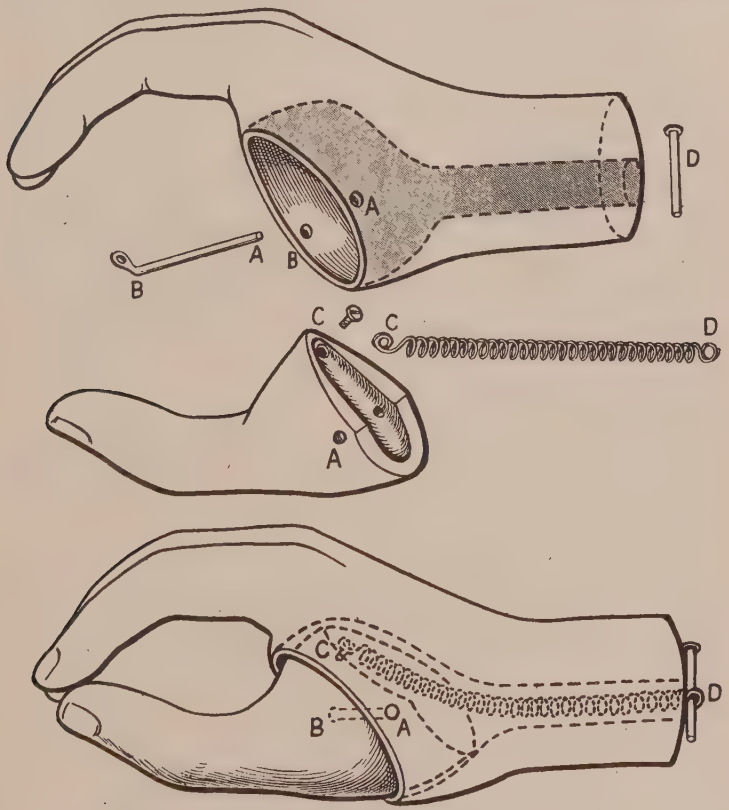
The Automatic Thumb.—Active opening movement can be produced by the mechanism shown in figure



FIGS. 139 to 142.—*Mechanism of the passive spring thumb.*

The thumb turns on the axle D upon a piece which fits by a tapered extremity C into a hollow cut out in the thenar eminence. The base of the thumb is rounded. The spring AB flexes the thumb.

146. A cord fixed behind the scapula of the opposite side by a ring which passes over the clavicle and under the axilla, extends down the posterior surface of the arm and forearm pieces, running in pulleys which keep



FIGS. 143 to 145.—*The Beaufort Thumb.*

The model shown on page 478 is more mobile than this, in which the thumb turns on the axis AB, and is fitted directly into the thenar eminence. But in this type it will be seen that the spring CD which keeps the thumb flexed, reaches right up to the wrist, and is therefore longer and more powerful. The thumb is much stronger, and this is the mechanism usually adopted. It has the inconvenience that it requires a deep excavation of the thenar eminence, encroaching upon the root of the index finger, so that it is impossible to mount the thumb in this way when it is desired to fit a movable metacarpo-phalangeal joint to the index finger, either with a spring (Fig. 155) or without (Fig. 148).

it in place. If the patient bends the elbow and at the same time brings the arm and both shoulders forward, rounding his back, the cord is tightened and pulls the thumb into the position of abduction and extension.

This narrow grip, between the tips of the thumb and index finger only, is not always convenient. A commerical traveller or a foreman could not easily hold with it the order book, in which he has to write. But if the thumb, held by a powerful spring, is parallel to the palm of the hand and grips against the other fingers, which are stretched out and not semiflexed, the grip will be strong and convenient, especially if a mechanism is introduced between the forearm and the hand, allowing the latter to be rotated at will into any position (Fig. 148).

As in the preceding case the thumb may have either a simple grip or an automatic grip opened voluntarily by a cord from the shoulder.

The following is a very interesting method which allows a fork or pen to be held, the automatic thumb being used. The fingers are half flexed, the index being separated from the middle finger, so that the handle of a pen can be inserted between them. The grip of the thumb is not against the tip of the index finger but against the outer side of the last phalanx of the middle finger, against which in consequence the handle of the object held will be pressed (Fig. 147).

The extended fingers are better placed for gripping than the partially flexed fingers, although the latter are convenient to the patient in certain ways. Ball and socket joints are inserted at the interphalangeal joints. (Details are shown in figures 152 to 154.) These are so stiff that they maintain the position

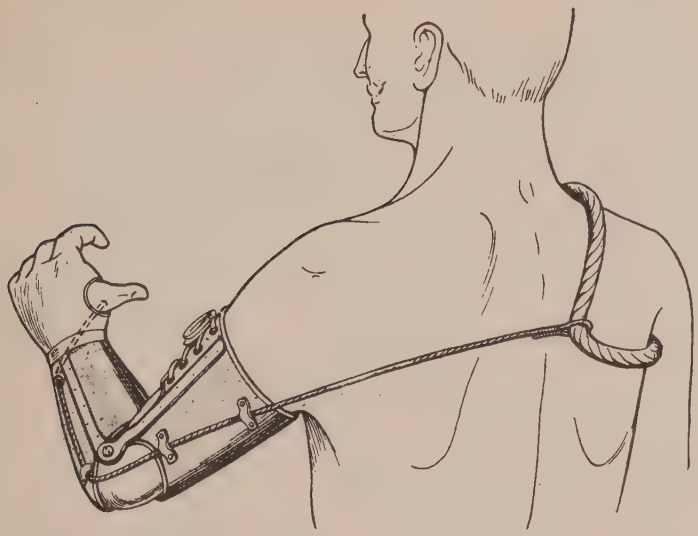


FIG. 146—Appliance with automatic thumb. The cord is fixed to a loop which passes round the sound shoulder. Abduction and forward movement of the shoulder and flexion of the elbow open the thumb.

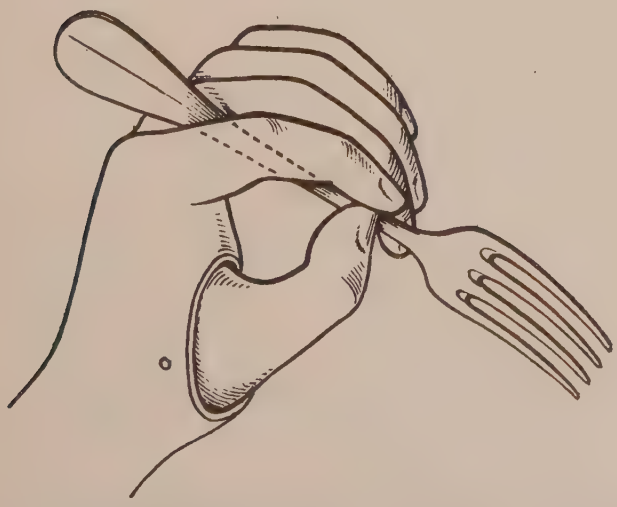


FIG. 147.—Hand with space between the index and middle fingers, wide enough to take the handle of a fork, which is held by pressure of the thumb against the side of the middle finger.

in which they are placed passively, as do the joints of an artist's lay figure.

If the fingers are rigid and in semiflexion it is

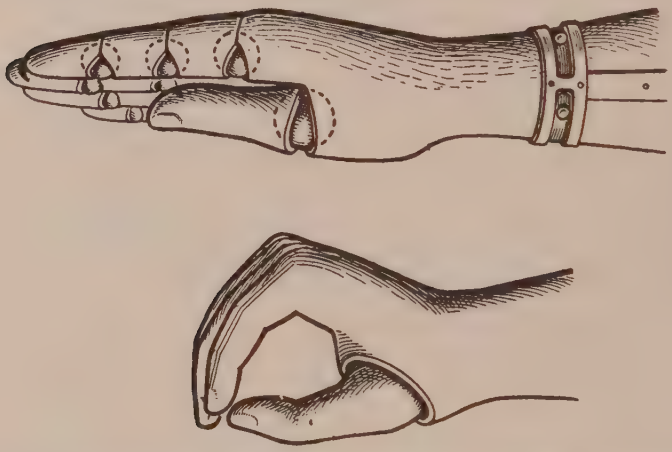


Fig. 148.—Articulated hand for commercial travellers. The thumb, lying parallel to the palm of the hand, takes a secure hold of such an article as a memorandum book.

Fig. 149.—The usual pattern of hand. The grip is too small.

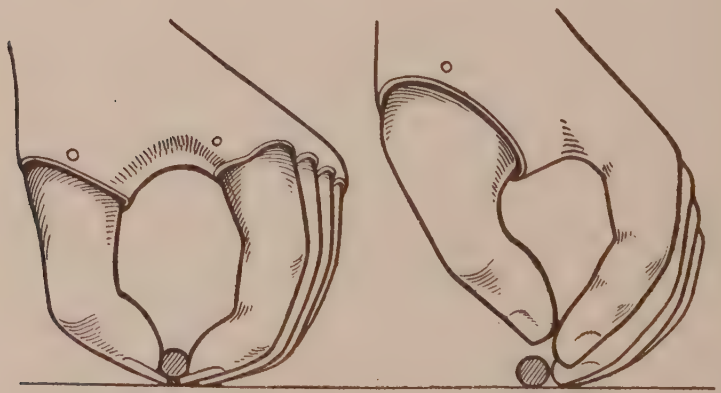


Fig. 150.—The index finger is the same length as the middle finger. The thumb and index fingers are furnished with nails. A small ball can be picked up.

Fig. 151.—The middle finger being longer than the index, the latter does not reach the surface of the table and the ball cannot be picked up.

possible to articulate all the metacarpo-phalangeal joints, fitting them with a spring, which keeps them flexed, and arranging for active extension as already described for the thumb. All that is necessary is to terminate the cord by five separate strings instead of one. In certain special cases this arrangement may be useful (Figs. 155 to 157). It seems to us useless to render the interphalangeal joints automatic.

As to the attempt which Beaufort appears to have made to give movement to the wrist also, we do not believe that any practical result has as yet been attained.

For the relative length of the fingers and the utility of a nail on the thumb and on the index finger see figures 150 and 151.

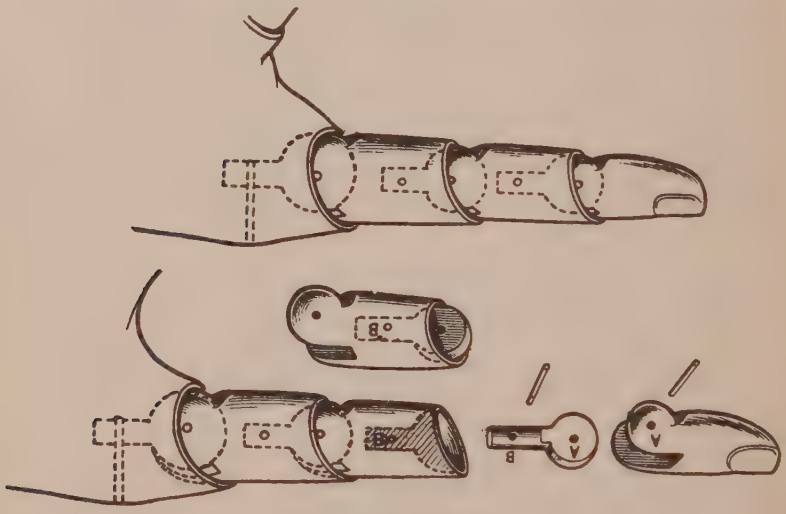
Shape of the Hand.

In the usual pattern (Figs. 149 and 151) the fingers are semiflexed and the thumb grips against the index finger, which is shorter than the middle finger as in the natural hand. If it is desired to pick up a ball, for example (Fig. 151), it will be seen that the middle finger projects and gets in the way. For this reason it is advisable that the index finger be longer than the middle, and in addition it is useful to furnish the thumb and index finger with a little projection representing the nail (Fig. 150).

In figure 148 will be seen an arrangement which allows the thumb to grip not by the tip, but by the whole length of its palmar surface (to hold, for example, a notebook). The fingers of this hand have ball and socket joints constructed in the way shown in figures 152 to 154. The joints keep passively the

position in which they are placed. The attachment of the ball of the joint on an intermediate tenon is similar to that of the thumb shown on page 478. The articulation of the index finger prevents the sufficient excavation of the thenar eminence for the insertion of the Beaufort thumb with its powerful spring. The wrist rotates upon a bayonet joint.

The fingers shown in figures 155 to 157 are joined

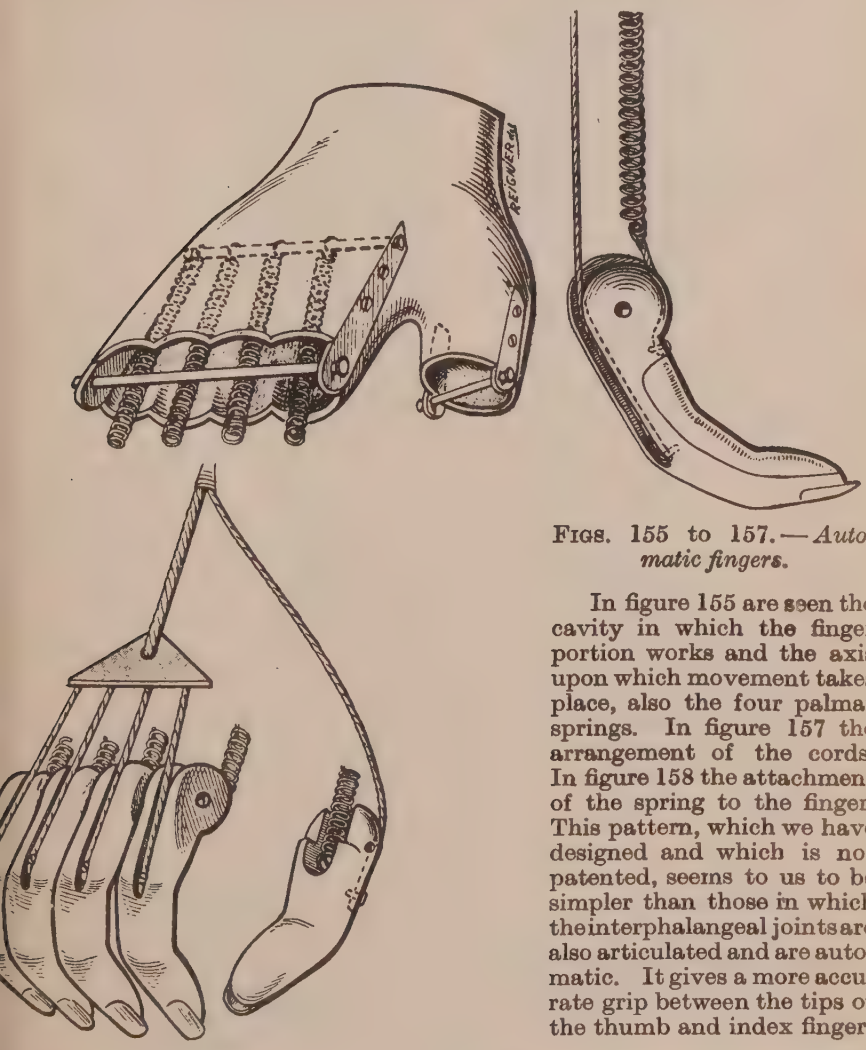


Figs. 152 to 154.

together into a single piece, which articulates with the metacarpal part of the hand upon a transverse axis.

They are held in a position of flexion at the metacarpo-phalangeal joints by four palmar springs and they are opened away from the thumb by the action of a cord which bifurcates from the thumb cord on the back of the hand. The pull of this cord is exerted upon the upper angle of a triangle from the lower border of which four cords pass on to the back of the phalanges. Figure 156 shows detail of a finger. We know that attempts have been made to isolate

by surgical means the masses of the extensor and flexor muscles in the end of the stump, making from them

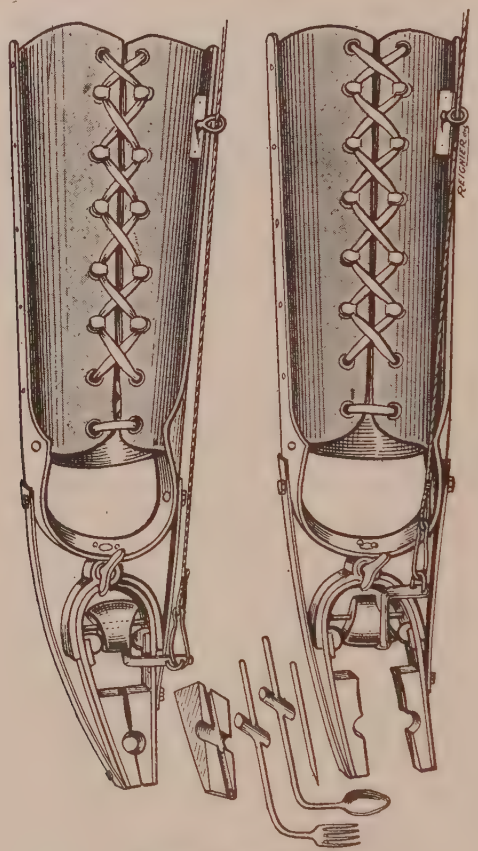


FIGS. 155 to 157.—*Automatic fingers.*

In figure 155 are seen the cavity in which the finger portion works and the axis upon which movement takes place, also the four palmar springs. In figure 157 the arrangement of the cords. In figure 158 the attachment of the spring to the finger. This pattern, which we have designed and which is not patented, seems to us to be simpler than those in which the interphalangeal joints are also articulated and are automatic. It gives a more accurate grip between the tips of the thumb and index finger.

little prominences, perforated with a tunnel which is lined with skin. The cords pass through the tunnels, and in this way are worked voluntarily. We are not sure that this is practicable.

The Brunet Grip.—The Brunet grip is described



FIGS. 158 and 159.

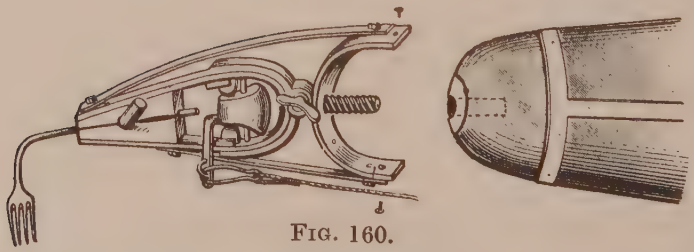


FIG. 160.

here because of its resemblance to the automatic thumb, both being worked on the same principles.

Brunet's Grip.

Below the leather forearm piece, which laces up, the lateral steels are continuous with each other in the form of an arch, to which the grip is riveted.

The latter consists of a strong semicircular piece of metal facing downwards, ending in a pair of wide and thick jaws, like those of a locksmith's pliers. When the apparatus is at rest, these are kept in contact by the pressure of two powerful fixed springs, attached to the semicircle on the forearm above and to the jaws below. The external and dorsal spring is attached to the tip of its jaw, the internal and palmar (the side on which the manipulating cord is attached) to the base of it.

The pliers are opened in the following way :—

Inside the semicircle to which the jaws are attached, lies a cylinder with its ends cut obliquely ; this rotates about a transverse axis, and when at rest lies with its longer side upward. To the palmar edge of the shorter side is attached a transverse eccentric, to which is hooked a cord actuated as described in figure 146. When this is drawn upward the cylinder rotates so that the wider side comes between the jaws of the pliers and opens them ; when the cord is relaxed the springs turn the cylinder back again and the jaws close. Figures 158 and 159 show the appliance at rest and with the jaws open.

This appliance is patented and is made in one piece. We demonstrate in figure 160 that it would be very easy to make the pliers detachable from the forearm, with a screw connection, just as is done in the various other appliances which will be described.

The grip of the automatic thumb always lacks power, for two reasons. There is no room in the thenar eminence to fit a powerful spring and the grip has always a very narrow hold.

The Brunet grip is an actual pair of pliers, shaped like these and furnished with a powerful spring. It is opened by a cord like that of the automatic thumb. Figures 158 to 160 explain the mechanism. It is an excellent appliance with which the wearer can carry out the majority of the actions of everyday life. It has, however, the disadvantage that it is not shaped like a hand—a point to which patients attach much importance—and, moreover, it is a part of a patented appliance, for which an interchangeable hand is not manufactured. So that in order to have in addition an artificial hand, which is capable of being removed and replaced by one or more of the appliances which will be described later, it would be necessary for the patient to possess two complete artificial limbs, and changing from one to the other would evidently be inconvenient.

We generally prescribe this appliance for patients who have lost both arms, for one side and as a supplementary appliance.

There are other similar models into details of which it is unnecessary to enter. Those in which the grip is opened by movements of pronation and supination are obviously only suitable for certain rare cases (very long stumps, with free movement).

B.—Appliances for Use in Place of the Hand.

The general principle is to fit to the end of the forearm piece an attachment which can be screwed on or unscrewed at will and which carries an appliance which is adapted to the various more or less specialised movements of the patient's trade.

Naturally the results thus attained must always be imperfect; but however little perseverance and ingenuity he may possess, the patient finds that he is able to educate the remaining arm, even when it is the left, to replace the amputated one in a way that is often remarkable. It is to this education that attention must be specially directed in the workshops for the re-education of the maimed.

1. *Knife and Fork.*—The first necessity is to be able to eat, and by certain very simple devices a fork,

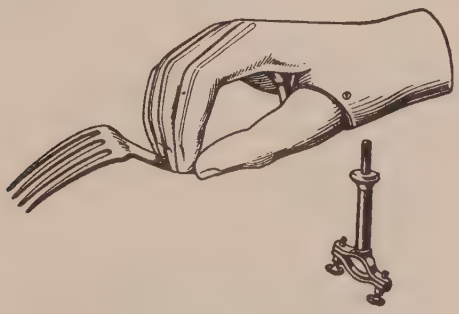


Fig. 161.—Raynal's fork rest.

spoon or knife may be fixed to a wooden hand, whether the thumb be mobile or not.

As a general rule if the patient has one arm intact, he uses the sound hand only for this purpose, but when both forearms have been lost an appliance is indispensable.

We have already described how in the hand with an automatic thumb, room can be left between the index and middle fingers for the handle of a spoon or fork. A direct grip can also be obtained with the hand shown in figure 147.

The hand with five automatic digits (p. 485) is usually arranged in such a way that it is possible to

hold a tumbler for drinking; but a patient with an amputation of one hand drinks with the other, and one who has lost both hands can drink with a straw.

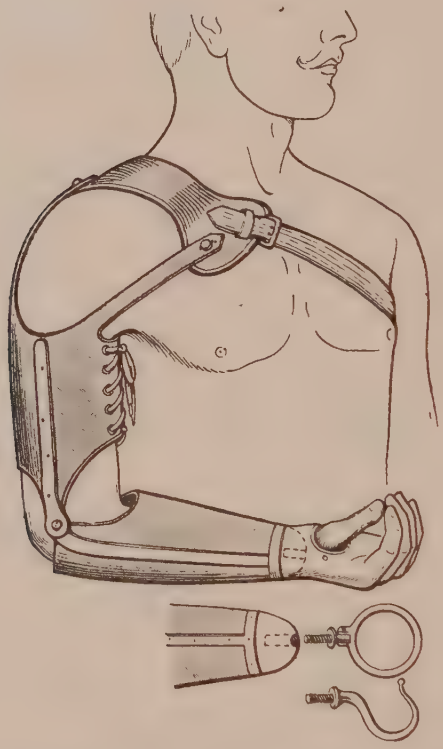


FIG. 162.—The termination of the forearm is a hemispherical piece of metal, furnished with a screw into which screw at will the hand, the hook or the ring.

These appliances have replaced that in which the knife or fork is attached to a block of wood which can be fitted into the palm of the hand when required. It is inconvenient to be obliged to carry these special implements about.

Raynal's fork-rest has the advantage over the last

mentioned that it fits any fork. Figure 161 shows very clearly its construction and the way in which it is used. The small special attachment, which is screwed in place, is not cumbersome and can quite well be carried in the pocket; it is, however, even more convenient to have an appliance which is capable of gripping the fork directly like those described previously.

Fig. 163.—Vine dresser's hook. (Gripouilleau).

2. *Appliances for Workmen.*—All the appliances that are attached to the arms in place of the artificial hand for performing various kinds of work are elaborated from two simple forms: the hook and the ring (for catching hold and carrying a parcel, for holding a handle, etc.). A glance at figure 162 will show the nature of these and the way in which they are used. But it will also be understood that if the simple ring and hook are useful for equally simple purposes they are altogether insufficient for skilled labourers

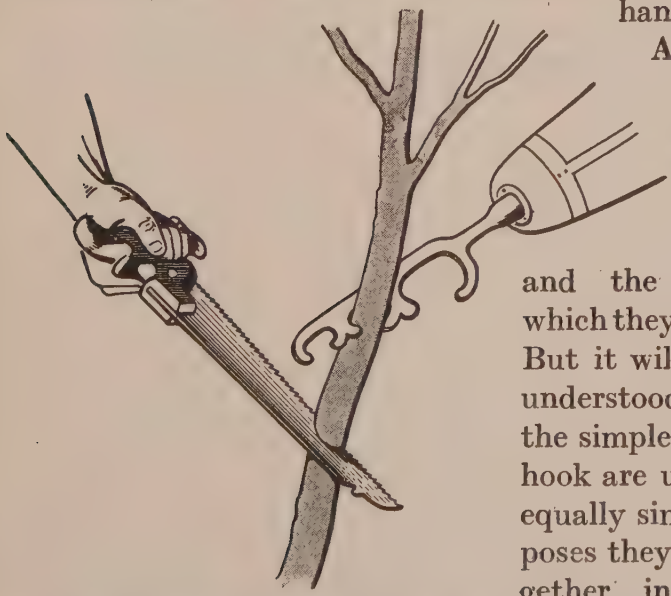


Fig. 164.—The branch is held in the grip by a leverage exerted by torsion.

whose work entails a certain special adroitness, *e.g.* joiners, locksmiths, agricultural labourers, etc.

Many makers have realised this and have devised very ingenious implements, some of which we reproduce, though we are obliged to limit ourselves to certain types, for they can be varied in countless ways according to the needs of particular cases. The same workman, as we have already said, may have several appliances which he uses in turn as he needs them in the course of his work.

These appliances are constructed in two ways; some are fixed to the end of the forearm and are immobile, some are attached by means of a joint or joints and are capable of rotation in various directions.

(*a*) *Fixed Appliances.*—We illustrate here an appliance derived from the simple hook, the *vine-dresser's claw*, devised some time ago by Gripouilleau; branches of varying size can be held while the other hand saws them or cuts them with the pruning shears (Figs. 163 and 164).

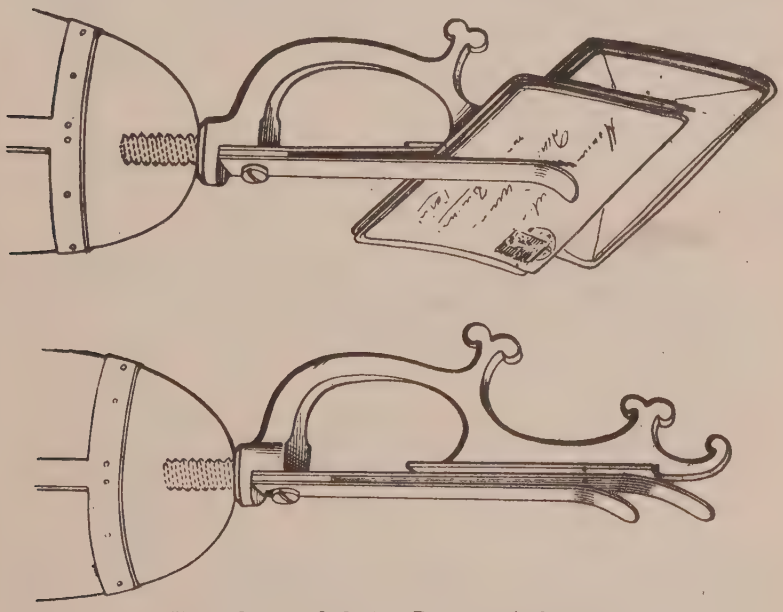
This appliance of Gripouilleau, with a series of hooks, forms the basis of almost all the "pincer hands" constructed by M. Bourcau and characterised by—

(1) The closure of the upper hook which is thus transformed into a ring, the two appliances being combined in one;

(2) The spring fixed to the straight side of the hook providing the grip necessary for holding articles. If the free end of the spring is turned up like the pointed toe of a mediæval shoe a sufficiently large opening is left between it and the straight edge of the hook to enable an object which is fixed mechanically or held by the other hand to be pushed into and gripped by the spring.

The simplest type of this mechanism is the *postman's hand* (Figs. 165 and 166).

The left hand of the postman who sorts letters has for its work to keep in the proper order the envelopes which are arranged in little packets; the right hand has only to push the letter into place between a flat spring, fixed to the wrist, and the back of the hook.



FIGS. 165 and 166. Postman's hand.

If two or three springs are supplied the postman can arrange two or three packets of letters at the same time. He can also bind the packet with string.

The vine-dresser's hand is provided with this spring to hold small flat objects, but the second spring is wavy in outline, so that semilunar spaces are left between it and the first. Into these branches slip when the spring is pressed against them, and they are thus held more firmly, whilst being sawn or pruned,

than by the twisting action of the old pattern hook of Gripouilleau (Figs. 167 and 168).

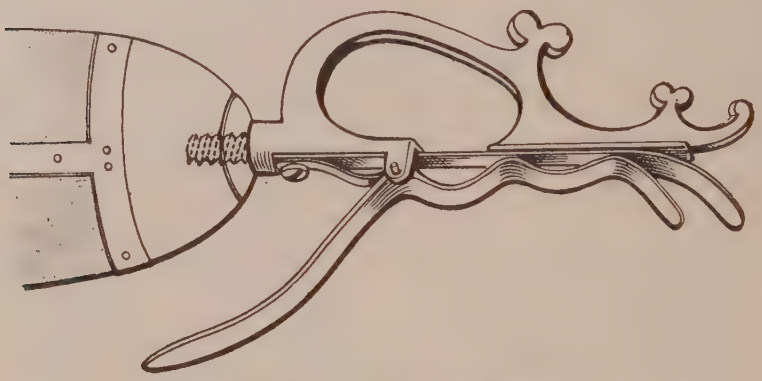


Fig. 167.—Horticulturist's hand.

This thrust to seize the branch is somewhat rough, and is only possible in holding hard wood which

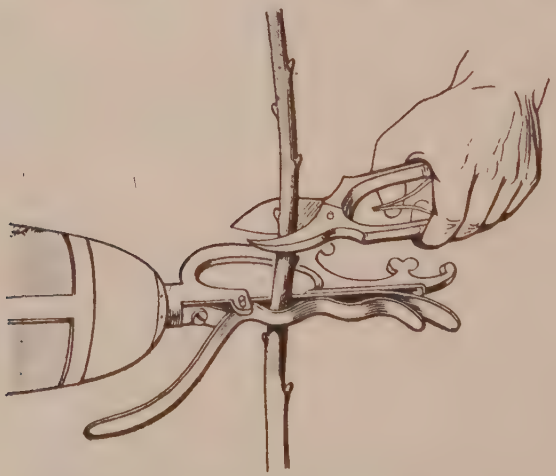


Fig. 168.—Method of holding a branch.

there is no fear of bruising. For more delicate shoots (grafting vines indoors, preparation of cuttings), a grip is necessary which can be opened before seizing

hold of the object. This is accomplished by prolonging the spring towards the forearm as a handle, pressure upon which against the chest (when standing), or against the knee (when sitting), opens the grip, in which the graft, for example, is then placed in the opening of the correct size.

The packer's hand is very ingenious (Fig. 169). It has the hook pierced by an eye enabling a thread to be passed through a basket as with a curved

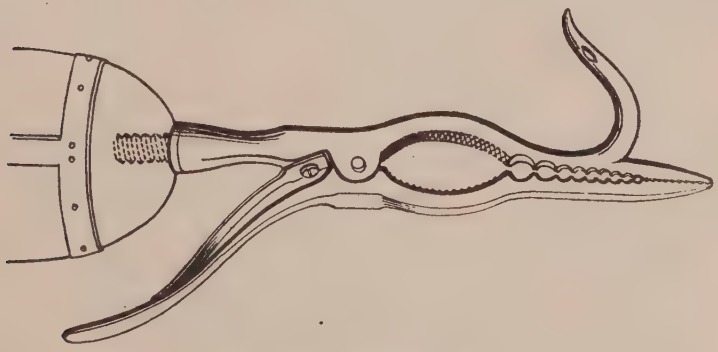


FIG. 169.—Packer's hand.

needle. The jaws of the pincers are smooth at the tips, but further back they have a series of graduated notches in which tacks of different sizes can be held whilst they are driven in with the hammer. But of course a workman can only work quickly if he can hold a number of tacks of the same size in the palm of his hand, placing one under the hammer, relaxing his hold of it after the first gentle blow has fixed it, and getting the next ready while he drives it home.

The plumber's hand (Fig. 170) is made in the shape of a pair of gas pliers, and ends in cutting edges with which wires can be cut. With them a bolt can be held whilst the other hand screws on the nut.

The leather-cutter's hand (Figs. 171 and 172) should be able to hold the skin which the other hand cuts: it consists of a plate with a rough surface

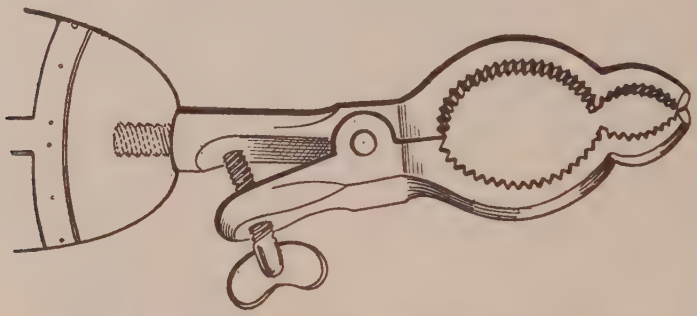


FIG. 170.—Plumber's hand.

fixed to a ball and socket joint which allows it to turn in any direction, so that the other hand can follow the line to be cut which is often sinuous.

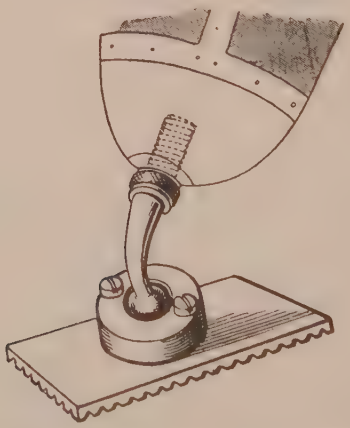


FIG. 171.—Leather-cutter's hand.

This appliance may also be used to hold a drawing paper, a rule for cutting cardboard, or sheets of paper for binding.

The examples that we have chosen amongst

Boureau's appliances for craftsmen will, we believe, be sufficient to explain the principles of their construction. These consist in studying the movements which are normally carried out by the passive hand (usually the left hand, but the right in left-handed people) and to devise an appliance accordingly, the sound hand always becoming the active hand.

We could have described many more examples, but we shall only say a few words about the *mechanic's hand*, which is simply an adjustable spanner which can

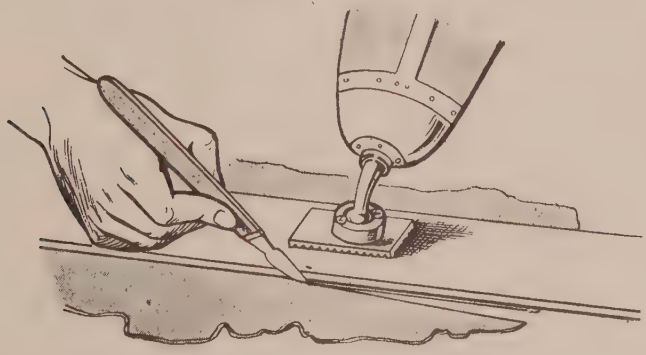


FIG. 172.—Leather-cutter's hand.

be automatically closed, terminating in toothed pliers to hold circular objects without the necessity for being screwed up. As a matter of fact, in all the work of a mechanic (sawing, filing, drilling, tightening screws, hammering, forging, and grinding) the left hand is only used for picking up and steadying the article to be manipulated. M. Boureau rightly considers that it is better to entrust this rôle to the artificial hand rather than to contrive to make the latter capable of sawing or of filing by means of the devices which we shall describe further on (p. 501 and following), ingenious and interesting though these may be.

From these appliances, adapted to certain particular grips, others have been devised for chair caning, soldering, and for enabling factory hands to work starting levers and brakes.

Thus each case must be studied separately and the workman furnished with one or several appliances according to his needs, making the necessary modifications from the existing patterns.

Several of these appliances are attached by a ball-and-socket joint like that described for the leather cutter: this is an intermediate form between the fixed appliance and the jointed appliances which will be described later.

Boureau recommends that the length of the forearm should be such that the artificial appliance reaches only as far as the level of the sound wrist. The work will then gain in precision. We believe that this principle holds good even for the true artificial hand, which should be made 3 to 4 centimetres shorter than the sound hand. But it must be realised that we shall be met with a difficulty, which we have already experienced. Comments are made upon the appearance of the arm and the wearer may sometimes be made to believe that this is due to faulty construction.

For certain special crafts the subject may be studied from another standpoint and an actual tool constructed which carries out the necessary actions like a machine worked by the forearm, so that in these special cases the artificial hand is the active hand.

At the Valentin Hauy Institute for the blind, where there has long been a brushmaking workshop, we have seen in use a very ingenious tool of this description

with a combined action for carrying out the entire manipulation of the thread which fixed the little

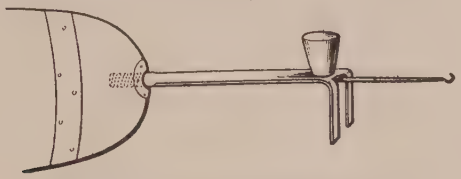


FIG. 173.—Brushmaker's hook.

FIG. 174.—First movement. The string is picked up by the hook.

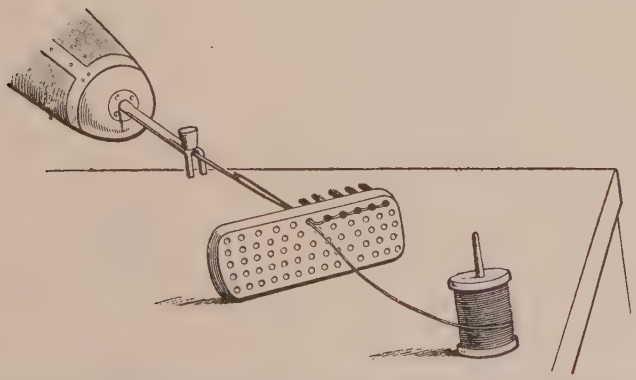


FIG. 175.—Second movement. The string is pulled through one of the holes perforated in the back of the brush.

bundles of bristles into the holes perforating the back of the brush. Results are so good that a blind and

maimed worker using this apparatus works more quickly than his comrades who have the use of both hands. It consists of a two-pronged claw surmounted

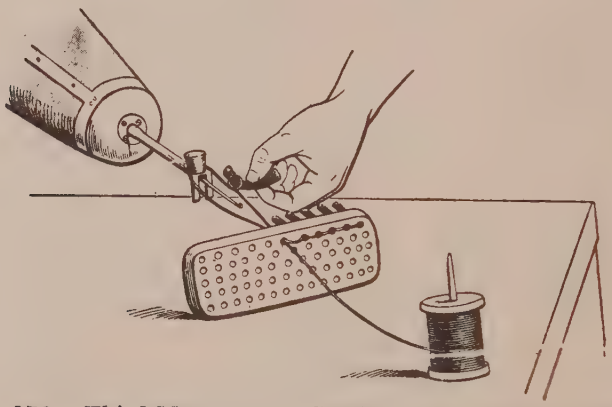


FIG. 176.—Third Movement. Catching the bundle of bristles.

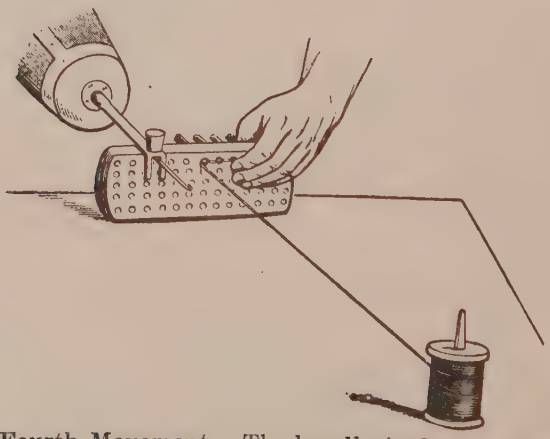
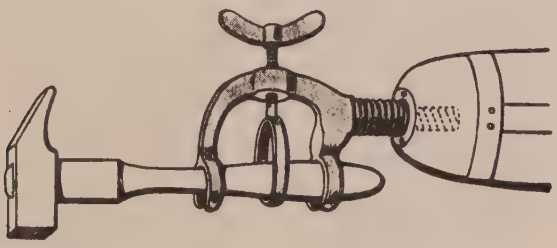


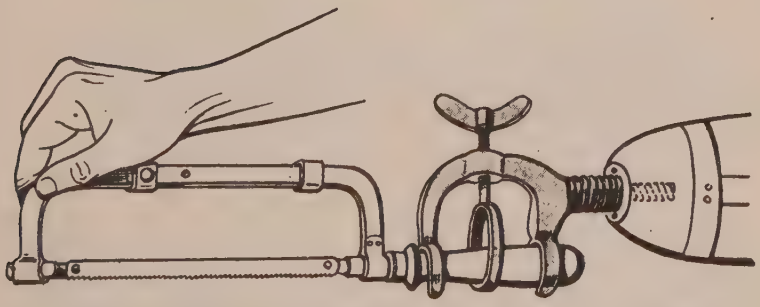
FIG. 177.—Fourth Movement. The bundle is fixed in the hole in the back of the brush.

by a small thimble-shaped projection and with a small hook, like a crochet hook projecting in front (Fig. 173). The hook first passes through one of the holes in the back of the brush, catches up the thread and draws it through the hole (Figs. 174 and

175). The thread is then looped around the thimble, whilst the sound hand binds the little bundle of bristles into a twist of the loop (Fig. 176), and finally the bundle is fixed into the hole, the claw being used to draw the brush towards the worker (Fig. 177).

(3) In place of an actual tool the detachable part may consist of a clamp on the principle of a ring into which the tool is inserted by the handle. The two



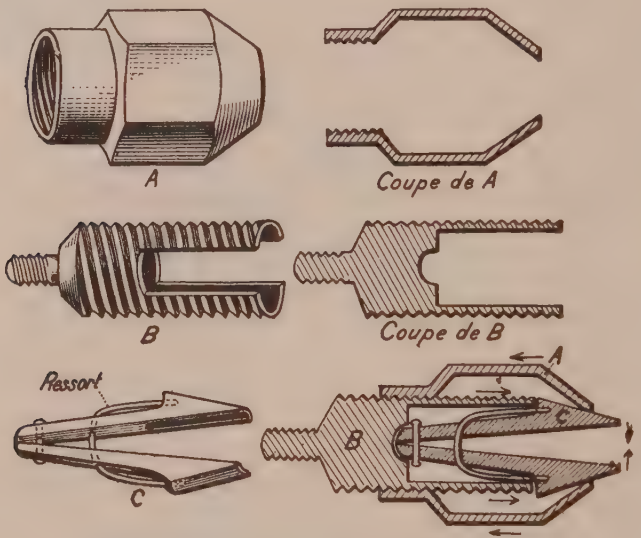


FIGS. 178 and 179.—Nyrop's grip for hammer and saw.

principal methods are the screw and the American chuck. A glance at figures 178 and 179 will explain how the large handle of a tool intended for heavy work is controlled by means of a screw and rings.

At Rouen we have seen the disabled Belgians who had been re-educated wearing an ingenious T-shaped clamp by means of which the handle of a tool may be held either in the line of the axis of the forearm

or at right angles to this. This method is specially useful for manipulating a file which is worked with one hand while the other, in this case the sound hand, presses upon the free end. Usually the filing is done backwards and forwards, working from base to tip of the file, but sometimes, specially for final



FIGS. 180 to 185.—*The American Chuck.*

The pincers are composed of two jaws with vertical cylindrical grooves (to fit upon a handle), joined above by a ring (Fig. 185) and coupled by a spring C which keeps them apart. The pincers fit into a piece B (Fig. 182) cut on the outer side with a screw thread (Figs. 182 and 183) upon which the piece A is screwed up or down (Figs. 180 and 181). When screwed towards the point of the pincers it presses on the two jaws and closes them. When screwed in the opposite direction the pincers open automatically.

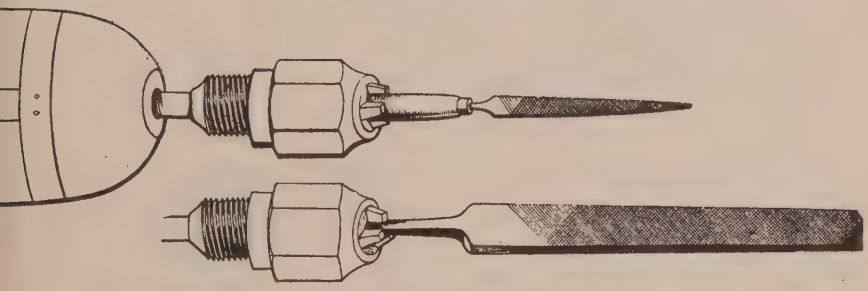
polishing, the file is held with both hands and worked from side to side.

The American chuck consists of a pair of metal jaws fixed at their base into a cylinder and appearing somewhat like the petals of a long corolla. Another cylinder is screwed over the first to control the opening

and shutting of the jaws. When this cylinder is unscrewed the jaws open and the handle of the tool can be inserted, when it is screwed up it closes the jaws and makes them grip the handle.

If the jaws open widely, the wooden handle of a tool can be held, but if the opening is small the unmounted tool must be fitted into them (Figs. 186 and 187). This method is specially useful for files, as it frequently happens that several files are required for the same piece of work and they can be changed rapidly.

It must, however, be insisted upon that the principle



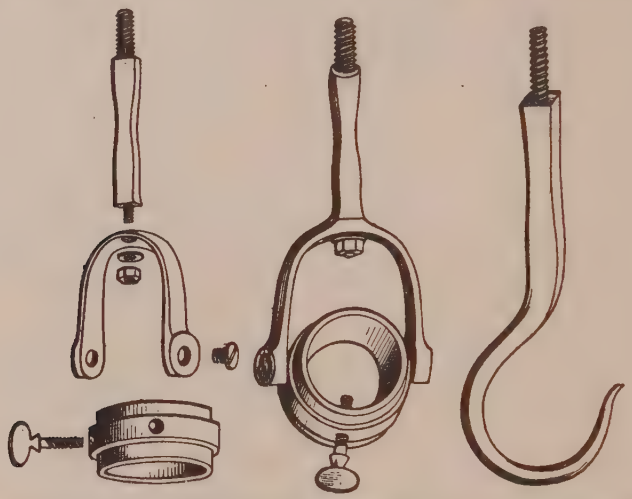
FIGS. 186 and 187,—File fitted into the American chuck.

of giving a passive rôle to the artificial hand is to be preferred.

(*b*) *Appliances with Mobile Joints.*—In the course of work the direction of the wrist is changing at every instant, flexion, extension, pronation, and supination occurring, sometimes in order to move around the object, sometimes in order to maintain a suitable position when the movements of the shoulder and elbow vary the direction of the forearm.

The consequence of this is that the worker learns to turn the piece of work around with his sound hand. To get over this difficulty passive joints are inserted

at the wrist, which allow the appliance to move when it is pressed against the piece of work and to take



FIGS. 188 to 190.—Agricultural hook and ring. (Gripouilleau.)

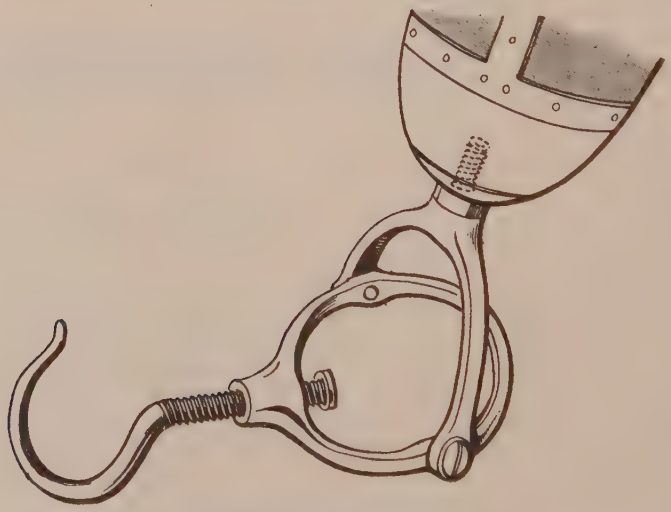
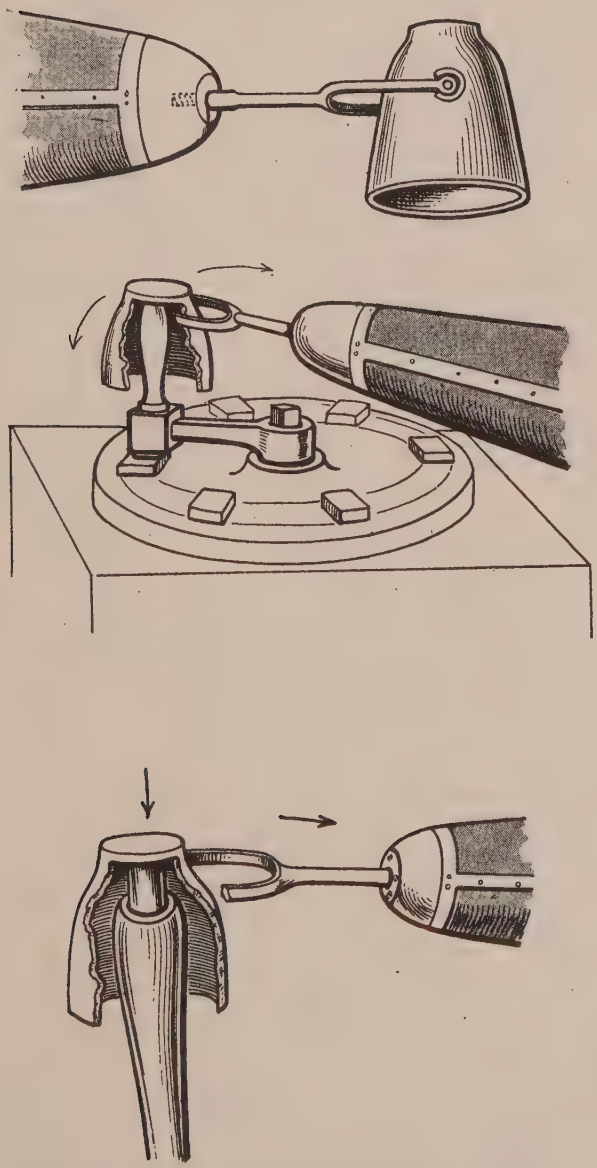


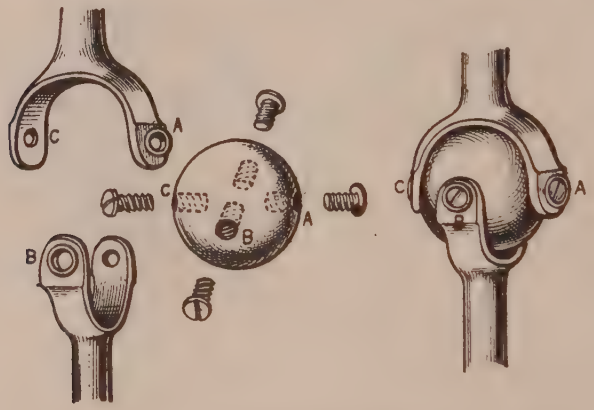
FIG. 191.—Combined hook and ring. (Boureau.)

up the direction which suits the inclination of the forearm.



FIGS. 192 to 194. 1. Tram driver's and chauffeur's bell. 2. Method of use by a tram driver. 3. Management of a motor car lever. Pressure at the extremity and traction.

One of the simplest mechanisms—and one of the oldest, because it was designed by Gripouilleau—is that of the *agricultural labourer's ring*, intended to grip and manipulate the handle of a wheelbarrow or a plough. The ring is mounted on a transverse axis and moves in a horseshoe which in its turn revolves on a shank which is screwed into the forearm. The ring is provided with a screw, which may be



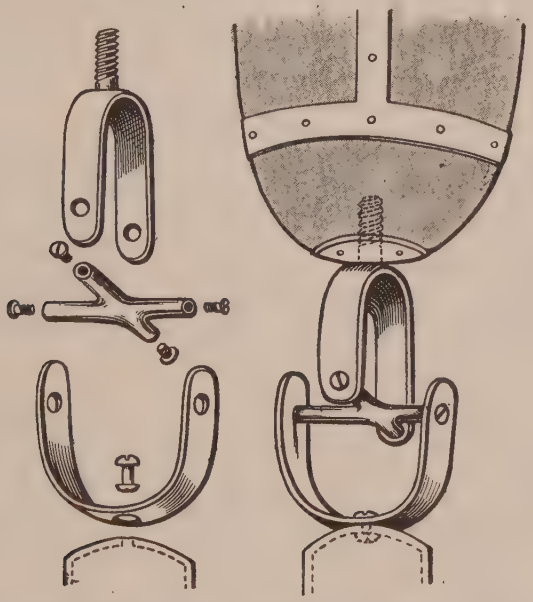
FIGS. 195 and 196.—Universal joint with ball.

tightened upon the handle if desired, but which is, however, rarely used (Figs. 188 to 190).

The tram-driver's bell, represented in figure 192, is devised on the same principle. It moves on a transverse axis, and in figures 193 and 194 its utility in managing levers in driving a tram or a motor car will be easily seen. The rotation of the horseshoe on the axis of the forearm is not required.

The "cardan" joint also allows movement in every direction: it consists of two semicircles of metal, placed at right angles, each working around a transverse axis, these axes being united in the form of a cross. The construction and working will

probably be understood without further explanation by a study of figures 195 to 198. The first two represent a system with a ball in the centre, which is well known commercially. The last two represent



FIGS. 197 and 198.—Simple universal joint.

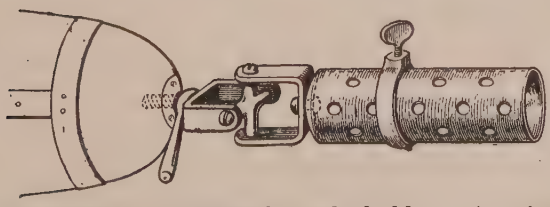


FIG. 199.—Gardener's cylindrical spade holder. A universal joint permits movements in every direction.

the simple universal joint generally used in orthopædic surgery. It is somewhat more cumbersome than the previous model.

The spade holder used at the agricultural centre at Limonest is mounted on a cardan (Fig. 199).

The joint can be fixed by a compression screw which is easily and quickly adjusted.

Where several tools are necessary each should be complete with its own universal joint.

Other methods of terminal passive articulations are—

(1) Ball joints which have already been described

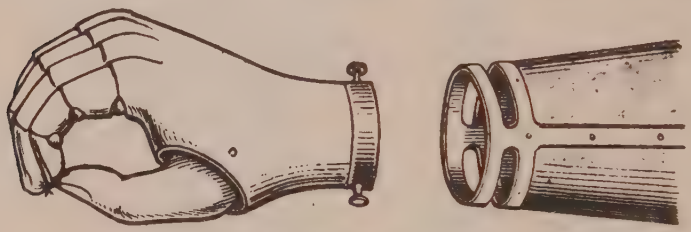


Fig. 200.

in connection with the fingers and which may be applied to the wrist.

(2) Bayonet joints which are only applicable to certain artificial hands which are not subjected to any great strain.

Figure 200 explains this mechanism as it is applied to the artificial hand represented in figure 148.

CHAPTER VIII

ARTIFICIAL LIMBS FOR AMPUTATION THROUGH THE ARM

In this chapter we shall deal only with amputation of the arm below the upper third, *i.e.* with cases in which the stump is long enough to transmit movements to the artificial limb. Amputation through the deltoid muscle must be considered in association with disarticulation of the shoulder.

Below the arm socket is attached an artificial limb which represents the elbow joint, forearm, and hand.

There are two types to be described :—

1. The artificial arm proper, which has the external shape of the natural limb.

2. The worker's arm, a terminal appliance in which outward appearance is not considered.

The considerations as to the arm socket and its attachment by a shoulder cap are the same for the two types of appliance.

Attachment and Arm Socket.—The surface over the acromion and clavicle is the only point from which support can be given to an appliance for an amputation through the arm ; the attachment is made by means of a shoulder cap.

The general shape of this shoulder cap and its

attachment by means of a strap passed under the opposite axilla are similar to those described for appliances for amputation through the forearm.

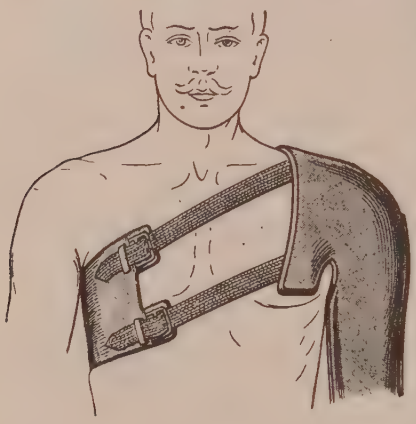


Fig. 201.

The larger the shoulder cap the more it extends forwards over the anterior wall of the axilla, upwards over the supra clavicular fossa, and backwards over the scapula, the more secure will be the support. The appliance is heavy and has no support other than the axillary strap. The latter has a tendency to ride upwards against the axilla where it exerts a pressure which may be uncomfortable. This may be relieved by attaching a vertical strap which is buttoned to the trouser belt.

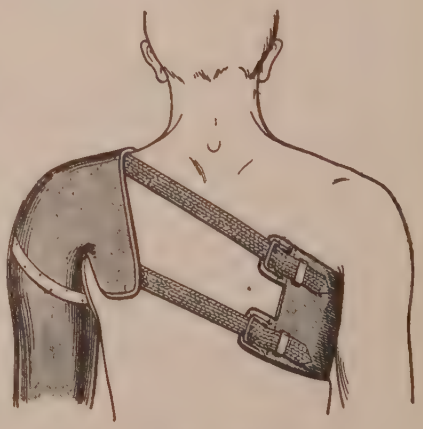
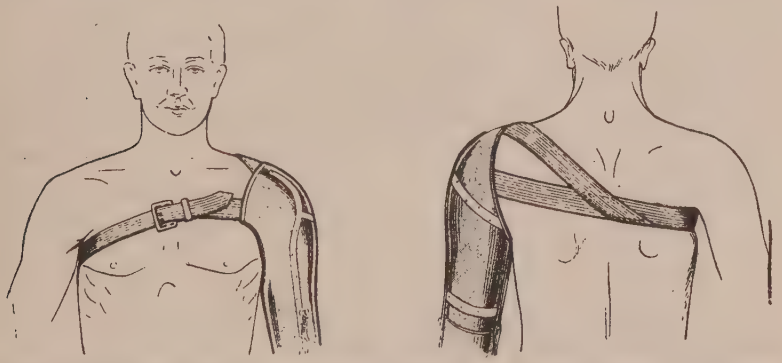


Fig. 202.

But although this extensive enclosure of the thoracic region may not hinder the movements of the stump forwards and backwards, it must obviously interfere with the movement of abduction. No doubt this movement is the less important of the two, but we ought to try to preserve it as far as possible.

In short stumps we must abandon it. But if the stump is long and consequently has no tendency to escape from the socket, even if this slips down a little, movement may be retained by two methods.

The first consists in separating the arm socket from a large shoulder cap, and inserting a joint between (see page 467); but the appliance is then heavy and cumbersome. Moreover, although abduction can thus be easily attained, thrusting and pulling movements



FIGS. 203 and 204.—Shoulder fitting of small extent allowing abduction.

require a light appliance, and finally it is impossible to secure rotation.

It is possible, on the other hand, by means of the other method, which consists in ending the shoulder cap at a line continued vertically upwards from the thoracic margin of the axilla. If the straps are strong and carefully adjusted the result is better than with the fitting over the scapula, so that this appliance is preferable. We here illustrate a method of fitting the straps which we consider a good one. From the posterior part of the ordinary axillary strap, a Y-shaped branch passes to the upper border of the shoulder cap above and in front of the clavicle, this

makes up for the small extent of the enclosure of the shoulder.

For the worker's arm a considerable enclosure without any joint is essential, in order to secure stability.

The arm bucket, usually continuous with the shoulder cap, is made of leather strengthened with steels.

The artificial arm is often abducted from the trunk, which constitutes an inconvenience. This is sometimes due to a fault in the alignment, the arm-piece not being at right angles to the shoulder cap. It is, however, more often due to the cylindrical shape given to the arm bucket which forces it away from the trunk. The inner side of the bucket should be flattened so that it may hang vertically close to the thorax.

The details of construction are different for the true artificial arm and the worker's arm.

1. Artificial Arm

The arm and forearm pieces are both made of leather. There is no object in making them to lace, the stump is enclosed in a socket in which it need not fit very tightly, because, as we shall explain, this appliance is unsuitable for heavy work.

These two parts are strengthened with steels, which are articulated by hinge joints at the level of the elbow. We have to study—

1. The position of the steels and the direction of the axis of the joint.

2. The lock to fix the elbow joint in a flexed position.

1. *Position of the Steels.*—The stump can transmit to the arm socket the various movements grouped under the name of circumduction, but its hold does not enable it to transmit rotation.

It is therefore undesirable—although usual—to attach the steels on the arm and forearm to the inner and outer sides of the limb. If this is done, as rotation is impossible, flexion of the forearm at the elbow can only be carried out in the sagittal plane. But this movement is only exceptionally required; the elbow being flexed to the right angle and fixed in this position by a ratchet the limb forms a hook upon which an object may be hung, provided that the forearm lies transversely in contact with the abdomen and not antero-posteriorly. Flexion should therefore be in a plane which is almost the frontal plane (20° or 30° in front of this), and not in the sagittal plane. As there is no active rotation of the arm therefore the steels must be almost in the sagittal plane (the anterior a little external, the posterior a little internal).

In certain carefully constructed appliances the arm bucket is cut transversely above the elbow and between the two parts a bayonet joint is fixed where the arm can be rotated by the sound hand, so that the direction of the elbow movement can be altered.

2. *Ratchet to fix the Elbow Joint in the Flexed Position.*—When at rest the forearm should hang vertically. But the hand can only be used when the elbow is flexed to an obtuse angle or a right angle, the latter position being more often used. Therefore when the patient has bent the joint to the required angle with his sound hand, he must be able to fix it in this position.

This fixation is effected by means of a ratchet

attached to the outer side of the elbow, which can be locked or unlocked at will.

This ratchet consists of a flat metal plate with a prolongation upwards shaped like the handle of a fork. The end of this prolongation is attached to the arm steel by a pin joint about 3 centimetres above the axis of the elbow joint. The plate is pierced by a rectangular opening, one border of which is notched ; it lies against the forearm steel, a catch projecting from which fits into the opening, this catch, situated 6 centimetres below the axis of the elbow, is of the same diameter as the notches with which it engages. The higher the notch with which engagement takes place the more nearly flexion approaches the right angle.

The width of the opening in the plate is twice the size of the catch, so that the joint works freely when the catch glides on the smooth edge and becomes fixed as soon as the catch engages in the notched border.

It is only necessary to arrange a lock, manipulated through the sleeve, to bring the smooth or the notched border in contact with the catch.

Suppose that the handle of the ratchet is prolonged behind the point at which it is hinged to the arm steel as a little lever furnished with a button, and that an elastic cord or spring is stretched from this button to a point on the postero-external border of the forearm, then if the lever points upwards and the notches are on the upper edge of the ratchet (as is the case in figure 205), the elastic, pulling the lever forwards, will press the ratchet down and make the notches engage with the catch on the forearm, if, on the other hand, the lever points downwards the elastic traction

will release the notches. The reverse occurs if the notches are on the lower edge.

It is then only necessary to arrange a mechanism by means of which this little lever can turn, with a stop which arrests it above at the vertical position, below at a point 45° beyond the horizontal.

A simple mechanism of this sort is shown in figures 206 and 207. The joint surfaces of the ratchet and of the little lever each bear a shoulder, the former

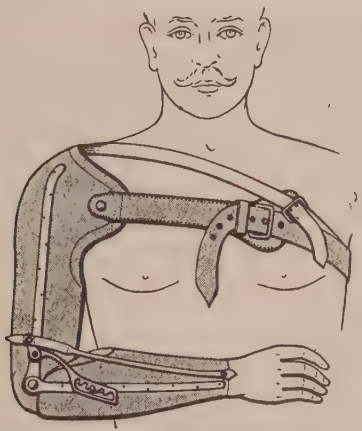


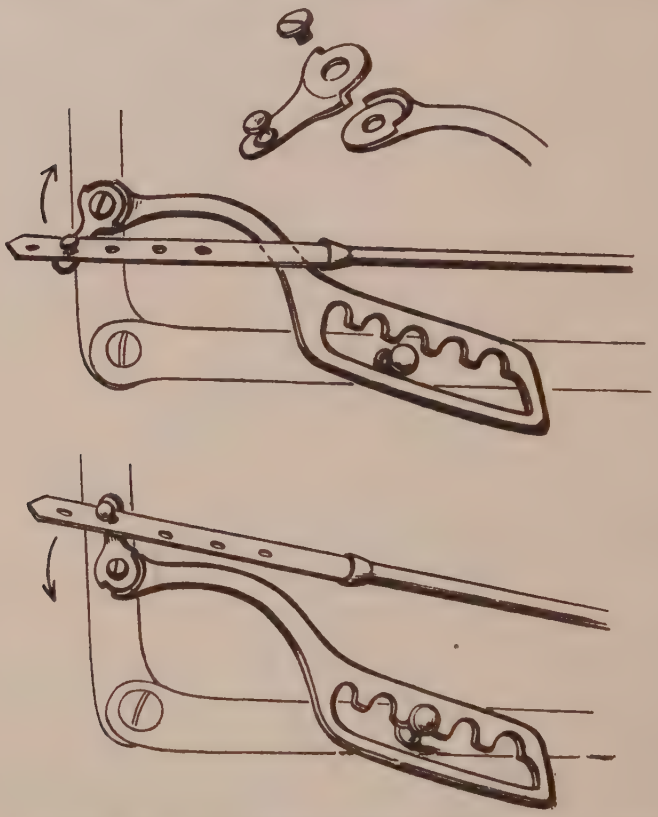
FIG. 205.—Elbow ratchet.

in front, the latter behind, extending over such a proportion of their circumference as will make them act as stops in the desired positions above and below.

A lock is thus provided which can be manipulated with the other hand.

In the particular pattern illustrated, traction is made by an elastic cord fixed to the centre of the back of the wrist and ending above in a leather strap pierced with holes which fix on the button of the lever. This arrangement allows of the adjustment necessitated by the gradual stretching of an elastic which is subjected to continuous tension.

A steel spring of this length (the whole length of the forearm) would be too heavy if it were sufficiently powerful. If it is desired to use this method the two ends of a powerful spring should be fixed, one to the



FIGS. 206 and 207.—The elbow ratchet and mode of action of its lock.

button on the lever, the other to the catch on the forearm with which the ratchet engages.

The spring should always be in tension. As the distance between the joint on the arm and any point on the forearm increases as the elbow extends, it is better for the ratchet, with notches on its upper

edge, to be engaged when the button points upwards and free when it points downwards. In the opposite arrangement, which is often used, the tension is considerable without being useful when the forearm is vertical, and the mechanism soon wears out.

3. *Hand and Other Appliances.*—The hand attached to the end of the forcarm has a spring thumb which may be passive or automatic. In the latter case, if the stump is long enough to allow considerable movements of the arm, the cord works in the way described on page467, for amputation of the forearm. If the stump is short, traction must be exerted by movement of the shoulders, rounding the back.

The hand with a mobile wrist is never used with these amputations except in certain expensive appliances, in which in addition the four fingers may be articulated, as described on page 481. For the ordinary limb these delicate mechanisms are devoid of practical utility.

It is easy to replace the hand with interchangeable appliances, but when the patient has to do hard work this is not a satisfactory method.

The arm with the ratchet at the elbow is in fact suitable for use by a clerk. But it is not either strong enough or simple enough for manual labour. In our opinion the functional and practical value of an artificial arm, particularly for amputation above the elbow, is often exaggerated, however it does exist, especially in many branches of agricultural work. For the latter the slightness of the lateral steels—and especially of the joints at the elbow—makes the appliance insufficiently strong. The necessary delicacy of the ratchet and its manipulation through the sleeve by the sound hand are additional disadvantages.

2. Worker's Arm

If our object is to fit to an arm stump an appliance which will be at the same time strong and flexible, capable of carrying out rough and even vigorous work, we must abandon the attempt to imitate the natural shape of the arm.

The movements and strength of the stump must be transmitted to the object held by means of a rigid rod at the extremity of which the appliance for gripping is fixed. It is possible to fix around this rod a show arm with a hand and a passive spring thumb for wearing on special occasions, in exactly the same way as we fit the show leg round the peg. Figures 208 and 210 will show at a glance how this is done.

But, as far as our present experience goes, this is only an accessory added for æsthetic reasons. The true worker's arm consists of a strong metal rod fixed to the arm socket in a way that we must now study.

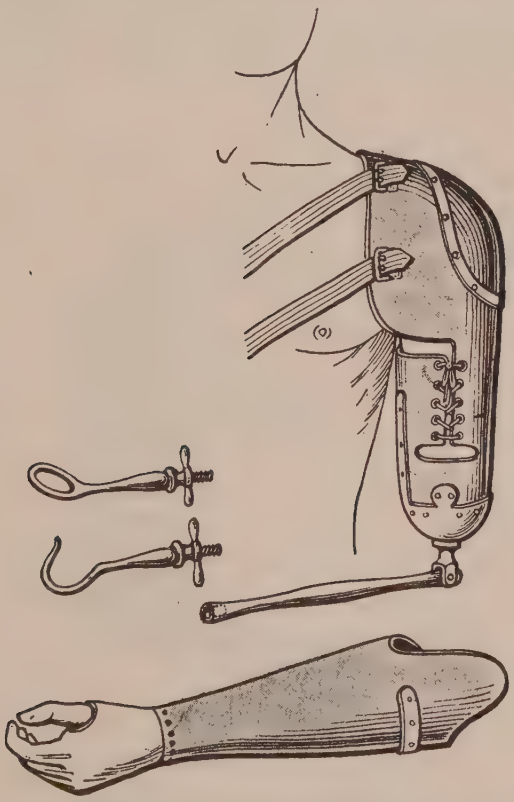
1. *The Arm Socket.*—We have already said that this must be continued into a shoulder cap of considerable extent, which may be perforated in the region of the point of the shoulder in order to render the appliance lighter. Abduction at the shoulder is thus sacrificed.

The arm socket is made of leather, open down the front and laced. By being laced it fits the stump more securely. It is strengthened by two steels which may be fixed in the frontal plane because, as we shall see, a passive rotation at the elbow joint is possible.

These steels are directly continuous below with a hemispherical steel cap, which is pierced in the axis of the limb by a hole into which is bolted the

connecting piece to which the rod which represents the forearm is attached.

2. *Articulation at the Elbow.*—The forearm consists of simple metal tube, attached beneath the arm



FIGS. 208 and 209.—*Worker's arm and show arm.*

The worker's arm consists of a metal rod which swings backwards and forwards at the elbow and also rotates upon the arm socket. To the end of this rod an appliance can be screwed (a ring and hook are here shown). Around the worker's arm a show arm with a hand (Fig. 209) can be fixed. They are shown in place in Figure 210.

socket by methods which depend upon the following principles.

The only movements that the stump can transmit

to the arm socket are forward and backward movements hinging about the shoulder, and abduction. The first of these movements is the only really useful one for the workman. The downward pressure exerted by active extension of the elbow no longer exists ; in order to press upon an object the

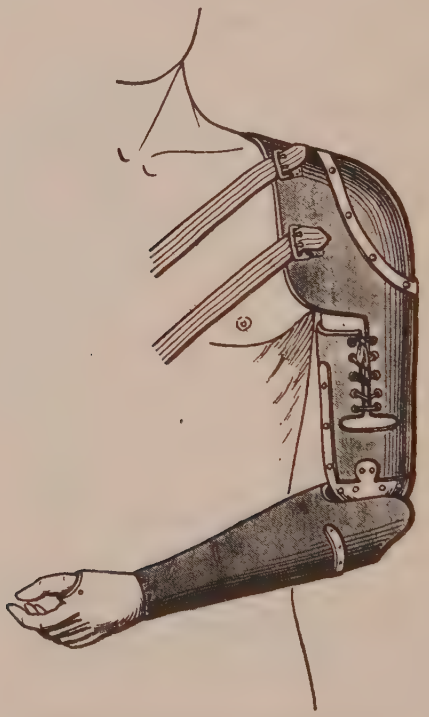


Fig. 210.—Show arm in position.

sound hand must be used, for it is not practicable to make use of the weight of the body thrown forward for this purpose.

In backward and forward movements—considering, for example, the use of the file—the angle at the elbow opens when the arm is thrust forward and closes when it is pulled backwards. These passive

movements of the joint must not be impeded in any way, that is to say, the forearm must swing freely below the arm upon a transverse axis and it must also be able to rotate freely around a vertical axis.

These movements are secured in the ploughman's hand which was designed sixty years ago by Gripouilleau and in which the joint which we have shown as a method of attaching the mobile ring to the wrist is utilised. The forearm rod attached by a strong transverse pin swings freely in a little stirrup-shaped cap, which itself rotates around a bolt by which it is firmly fixed into the metal or wooden hemisphere which terminates the arm socket.[1]

It is clear that this complete liberty of action has its disadvantages; the elbow joint can never be made to assume a fixed position against any passive resistance; moreover, in actual practice the useful range of either of these movements is small. For this reason attempts have been made to devise methods by which they can be limited in the various worker's arms which have been designed since the beginning of the war. In all these arms the mechanism of the elbow joint is derived from that of the ploughman's arm of Gripouilleau. Unfortunately none of these mechanisms in which a pressure screw is used for fixation possess any strength. At first sight, in a new appliance they appear attractive and work well, but it is well known to all mechanics that the thread of a screw which is in constant use quickly wears and then it is impossible to tighten it.

At the extremity of an artificial arm, whether it be an arm of natural shape or a worker's arm simplified to the form of a jointed rod, any of the appliances

[1] Wood, which was used by Gripouilleau, has been given up.

already described for forearm amputations can be screwed on as required.

It is by the use of these appliances that Gripouilleau's old ploughman's arm, which ended in an interchangeable hook and ring, has been improved.

Apart from their actual economic value, results have been obtained by use of these terminal appliances, in many different skilled trades, which are of the greatest possible interest.

For reasons that we have indicated in describing the attachment of the elbow, the various attempts that have been made to give to the wrist a mobility that is under control have not so far led to the invention of an appliance that is both strong and durable. For this reason we consider that until something new is designed it is better to make the terminal appliance a fixed one.

CHAPTER IX

ARTIFICIAL LIMBS FOR DISARTICULATION THROUGH THE SHOULDER JOINT AND AMPUTATION THROUGH THE DELTOID MUSCLE

So far as function is concerned these operations are identical; a short arm stump is incapable of transmitting movements to the socket of the artificial limb.

That is to say, our appliance will be a purely passive one, and at the present time it is useless to attempt to make any sort of worker's arm. We must aim simply at supplying a limb which imitates the external shape of the arm, with an elbow joint which can be locked with a ratchet. At most it is possible by a movement of the opposite shoulder to work an automatic thumb by means of a cord, as a rule, however, a simple spring thumb is preferred.

Nothing need be added to what has been said in the previous chapter about the elbow joint or the hand.

In the fitting of an attachment over the shoulder the amputation through the deltoid presents an actual advantage. For in this case the shape of the point of the shoulder is preserved, and the attachment

carried out as described on pages 467 and 510 fixes the appliance very securely.

If the entire humerus has been removed a very extensive enclosure of the front and back of the chest is essential and in order that the axilla may be in close contact with the top of the limb it is a good thing to stretch across this space a layer of some firm material.

These appliances can be used to steady a piece of paper upon which the patient is writing, to carry a parcel which is not too heavy with the elbow flexed, to grip an article with the thumb. A workman who is being re-educated for some occupation which is possible for a one-armed man, will usually—unless he is going out for pleasure—leave his artificial arm at home in the cupboard.

CHAPTER X

SOME GENERAL PRINCIPLES IN THE RE-EDUCATION OF THE DISABLED

When a disabled man has been fitted with an artificial limb he has to learn a trade which will enable him to supplement his pension and provide for himself and his family. In our opinion, which we believe we have expressed more than once in this book, it is nearly always advisable to determine what profession will ultimately be possible before ordering the artificial limb. This principle is perhaps not always thoroughly understood, although there are fitting centres where it is fully recognised (a proof of this may be found in a recent article by Nové-Josserand and Bouget).

It is unnecessary to repeat that whilst every effort must be made to associate form with function, the latter is bound to take precedence of the former. It is, however, not always easy to impress upon patients, and more especially upon their protectors, that *form* is for Sundays and holidays, and *function* is for workdays.

The grave problem of re-education of amputation cases, and in a more general sense of all the maimed, now confronts us. We believe it to be worth while to indicate the general principles so far as they are at present understood.

I

At the outbreak of war the idea of the disabled in general, and particularly of those who had had a limb amputated, was often to give up any really active trade and to seek a "situation" generally as an official with no actual manual labour. It must be confessed that many people, especially the nurses, encouraged them in this, and possibly the latter would not deny having done so.

It has rapidly become evident that there are too many maimed to be supplied with situations as caretakers of public gardens or doorkeepers, and that they will not be able to gain a living by making tricoloured decanter-mats of string or rafia or artificial flowers, when bazaars organised for their benefit by tender-hearted souls have gone out of fashion.

One of us was present a short while ago at the following little scene :—

In a hospital where there were two amputation cases, one through the lower fourth of the thigh, the other through the middle of the leg, both agricultural labourers, a distinguished man of letters, actuated by the best intentions, asked them what they counted on being able to do after they had been fitted with artificial limbs. The first replied that he hoped to return to agricultural work, the second that he would never be able to do that but would look out for a "situation." Our friend was much surprised to hear us say that he would be ill employed in using his influence to obtain his desire for the second patient, because a man with only one leg could work on the land with almost no diminution of his ordinary capacity, even with the old-fashioned kneeling peg leg.

As Jean Camus has well said in a recent article in the *Paris Médical*, "We are beginning to pass beyond the phase when re-education of the maimed was left to chance. It is felt now that the frivolous efforts of benefactresses who, acting with the best intentions but without reflections, are delighted to be able to transform into a shorthand typist an honest farm labourer who had a strong attachment to the soil and could quite well return to it, must be avoided. Such feats are both culpable and absurd."

These fantastic ideas must be got rid of, and all our efforts must be co-ordinated, the complexity of the conditions to be dealt with being duly weighed.

Given a maimed man the first care should be to educate to the maximum all the uninjured and remaining parts. It is too often forgotten that among the parts remaining the brain plays a leading rôle, even the chief rôle, not only because it is the organ of "good will" without which all attempts at re-education are fruitless, but also because good will being given the intelligent man will succeed better and will be able to adapt himself to more delicate work. "Physiotherapy cannot be prescribed," says J. Camus, "as quinine is prescribed. The malarial patient who takes the latter medicine benefits whether he wishes to or not. The wounded man who submits each morning to his mechanotherapeutic treatment does not recover unless he wishes."

It is very difficult to make the layman understand this. He invariably takes for granted the good will of the patient, with all of whose complaints he sympathises, without for a moment realising that they sometimes degenerate into jeremiads, often with an ulterior motive. An examination by a doctor—

and an experienced doctor—is therefore necessary in order to determine under what physical and mental conditions an amputation case can be re-educated; so that he may understand that it is entirely to his interest to work as quickly and as well as possible, that begging is degrading, and above all that private charity is temporary and exhaustible; and that in consequence he must as quickly as possible put himself into a condition to supplement by a salary justly earned the pension or gratuity which is certain to be insufficient for his maintenance.

It can never be sufficiently insisted upon in dealing with the maimed that by resuming work, and on account of the functional improvement resulting from doing so, they need have no anxiety that their pension will be reduced, because the amount of this is based on the extent of the injury itself and on the man's rank, and not on his profession before he became a soldier. In the same rank the pension is the same for a surgeon or a lawyer, if both have lost a hand.

It is a deep-seated notion, instilled into the minds of injured workmen by the often suspicious folk who advise them, that if they begin work before their case has been settled their pension will be less.

It must be acknowledged on the other hand that the civil expert is often faced with a difficulty. As our law stands—and it is unfair—work cannot be resumed partially with provisional half-pay followed later by whole-time work with permanent salary. This difference is important to our wounded soldiers, who have everything to gain by a rapid and complete re-education and whose duty it is to do whole or part-time work while their legal position is being arranged and before the wound, in legal phraseology,

has become "consolidated," that is to say, before the completion of treatment.

It is only fair to add that the patients are not alone to blame and that the administration has for long been guilty of an error against which reaction is growing, viz. delaying re-education until the time when the local condition has become permanent and the patient has been discharged and has received his prosthetic apparatus.

This delay is deplorable, on both medical and social grounds. On medical grounds because in very many cases before treatment is quite complete the addition of carefully graduated and supervised work is an important part of the treatment. On social grounds because it is necessary to fight in every possible way against the common tendency of the patient to fall into habits of laziness and intemperance.

This is now understood, and almost everywhere to-day the wounded soldier can resume work in workshops attached to the centres of physiotherapy, and thus begin his re-education while continuing his treatment.

At a certain stage resumption of work becomes the best therapeutic agent of all.

It is obvious that this resumption of work cannot supply the place of certain special treatments such as electrical treatment during the regeneration of a nerve, balneotherapy, or graduated gymnastic exercises; but is it not true that work with its continual active movement is infinitely superior to passive mobilisation by means of apparatus however ingeniously the latter may be contrived? Morever it is surely a more efficacious course of mechanotherapy when the patient works for half

or all the day than is provided by the special course occupying only an hour or two.

The tendency to-day is in this direction, as, for example, at the Grand Palais, thanks to the efforts of J. Camus, and also in the agricultural centre of the XIIIth district under the direction of Belot and Privat. At a given moment all treatment may be suspended and the patient may devote himself exclusively to work with results the excellence of which Nepper and Vallée have demonstrated.

The workmen are then eligible for work in a town in private workshops, but so far this freedom has more inconveniences than advantages. A man whose working capacity is much reduced, and more especially a man who requires re-education, has no place in an ordinary workshop where neither the proprietor nor the foreman nor his fellow-workmen are in truth much inclined to concern themselves about him. Where actual education is necessary this is best supplied in special workshops where the patient will be among comrades handicapped like himself, whose progress he will be able to watch and whose efforts he will imitate, rather than among able-bodied workmen, by comparing himself with whom he is bound to be discouraged.

The problem has been solved by the Belgians in a remarkable establishment opened at Port-Villerz, and by the Austrians at Vienna under the direction of Spitzy, as Nové-Josserand and Bouget inform us, by delaying a maimed soldier's discharge from the army until his re-education is as complete as possible. This method has proved to be to the interest both of the individual and of the State, but we do not seem to have considered this solution, and it is still to be

feared that it would accord ill with the independence of our national character. The actual fact, though it has not been brought into prominence, is that our usual system of "watertight compartments" has been applied by adding to the centres of physiotherapy centres of agricultural or industrial re-education, the results obtained in which are dependent upon the efficiency of the director of physiotherapy.

This matter seems to have received very little special attention in connection with amputation cases. It is, however, of great utility to develop the strength and agility of the remaining limbs by suitable gymnastic exercises, to teach a man with only one leg, for example, to jump without an artificial limb and to climb a slippery rope or a ladder; or to train the left hand of a man who has lost his right; to develop the greatest possible strength in the stump by training it in movement combined with the exertion of force. In addition to this, early and provisional equipment with artificial limbs must become general. These temporary limbs are undoubtedly rudimentary contrivances, but they are functionally good and are useful on account of their mere weight.

In this connection the temporary arms used by Nové-Josserand and Bouget in their agricultural re-education centre are very interesting models. The great advantage of using a temporary limb is that the time required for the construction of the permanent apparatus, often a considerable period is not lost in idleness, the mother of all the vices.

II

It was said at the beginning of the last chapter that whenever possible a disabled man should be

given a real trade and not one of those frivolous and trifling occupations which were at one time the fashion.

In the choice of a trade the ruling principle is that of aiming to restore as nearly as possible the man's former occupation. This principle should not, however, be carried to an extreme.

As Camus has justly said, by his previous work a man has stored up a mass of ideas, a fact which is too little realised, especially by himself. These include the manner of choosing, holding, and attacking the materials upon which he works, and of appreciating their qualities and faults ; knowledge of their market value, of the value of the labour, etc. This should be utilised in his future work even though it be realised, as M. Bourillon has remarked, that the resumption of his trade in its entirety may be impossible.

With the tools that have been described a man who has lost his forearm may be able, for example, to undertake a locksmith's work and to execute correctly all the movements required in plying the trade. Granted ; but how long will he take to make one piece, let us say, as well as his neighbour ? If he produces little he will not find an employer to give him daily work, while if he does piecework, apart from the fact that it is not in good repute among those who are the actual leaders of the working classes, it will not be remunerative, and to earn 3 frs. a day when a comrade earns 10 or 12 frs. is practically an impossible solution.

The case may be cited of a woman suffering from congenital deficiency of the hand with a very short rudiment of the wrist which is only slightly mobile.

By means of contrivances which we need not describe, and with no prosthetic apparatus, she threads her needle and sews as quickly and as well as anybody. This is not an argument, for: (1) it is a congenital lesion and the educability of a child is well known; (2) the woman is extremely intelligent, and unhappily this favourable factor cannot always be counted upon. It would be wrong to conclude from this that a case of amputation at the wrist should be put to sewing.

It must never be forgotten that intelligence and will are factors of the first importance, so that however little intellectual capacity the disabled man may have, he is bound to profit by his passage through the school of re-education in learning to read and write if he is illiterate—this is more frequent than is usually believed—or to improve his knowledge if he has already had some instruction. It is in fact, by brain work that many learn to replace their physical defect. Let us take, for example, a disabled bricklayer. If he is intelligent and is given a helping hand in the shape of the necessary instruction, he may become a builder on his own account in a small way when he knows how to make plans, work out estimates and keep accounts.

This is not a Utopian fancy. In the small towns and villages there are many owners of businesses such as masons, decorators, joiners, etc., workmen who cannot spell, but who are intelligent, have business minds and a gift for overseeing, who have given up the trowel and will build you a house as well as, or often better than, many "architects." It is with similar aims to these in view that a bricklayer should be re-educated when it is judged that his intellectual capacity is sufficiently great.

Where there is no intelligence education can do little. There are in civil life innumerable "casual labourers" with limbs intact who have never been able to learn a regular trade and who earn a miserable livelihood by doing what "turns up." Their situation becomes serious when they lose some of their physical capacity. They can, however, be rescued, particularly by encouraging them to become agricultural labourers. It is indeed especially agricultural labourers who should be urged to return to the land, and those mechanics who will be unable to work in a factory for the future should also be encouraged to take up this work. One reason for this is that the workman's arm—especially if it has not been too much elaborated—is useful for the execution of a considerable variety of work on the land. It is unnecessary to speak of cases of amputation below the knee, since their usefulness on the land may be taken for granted.

In the country as a matter of fact a man never dies of hunger; and this cannot be said of the town. Apart from actual cultivation of the land, which is in part impossible for the maimed, there are numerous and important occupations of which a town dweller would not think. It is when he goes to the centre of re-education in agricultural work, first of all to view it and then to work, that the disabled man takes note of what he can or cannot do, and of the work in connection with agriculture which is open to him, such as poultry rearing or bee keeping.

This applies to other employments than agriculture.

Apart from his actual trade which the workman can no longer ply with a sufficient return for his labour, he may be able to work at one or two of the accessory employments which would not of themselves

bring him in a living but which would yield a satisfactory supplementary income.

In certain re-education centres there seems to be a marked predilection for crafts in which the apprenticeship is short and the installation costs little, though these are in fact the characteristics of those trades which give the labourer a poor return, that is to say, time-work in a large or small workshop.

At the beginning of the war an attempt was made to show that there would never be enough tinkers, sabot makers, shoemakers, or saddlers in the country. It is quite a false idea that a disabled man can gain a living at one of these crafts in a village. It is true that he can do so if, working as an agricultural labourer, he can act as a barber in his spare time, and is capable of executing small jobs, especially repairs, which the villagers would readily give to him rather than have to go several miles to get them done. When the disabled man has this additional work in his hands he will gradually be able to ascertain whether the needs of the countryside and his own personal capacity are compatible with its development. In that case, however, he will be, in fact, a small proprietor buying his own tools and materials and fixing a retail price. But the great majority of workmen have no notion of such calculations and such organisation as are indispensable when a man runs a business even if he is alone. It follows, therefore, that the education of his mental, and especially his commercial, faculties must be considered, and it must be ascertained whether the man is likely to profit by such education. It is useless to install in a hamlet a shoemaker who is incapable of working except as an assistant, and in the town at the actual factories the prospects are poor.

Moreover, conditions of life in the disabled man's native place must be considered as a matter of importance. A man from the Mediterranean country has no idea beyond the cultivation of meadows, and one from Picardy none beyond the making of cane baskets for packing flowers.

Judgment is difficult, and in order that the choice may be exercised as reasonably as possible, the careful collaboration of the patient, the doctor and the managers of the workshops is essential. We repeat that this is one of the principal objects for which the centres of re-education are useful. There are some efficient men, we know, who without asking anything of anybody find quickly and unerringly the exact work that suits them. There is no need of anxiety in such cases.

A certain metal worker from the invaded area suffering from pseudarthrosis of the shoulder, whose wound we were treating, sent for his wife, and they began to rear geese. We know two cases of amputation of the right arm, an operative at an aeroplane works and a worker in stucco, who during their stay at hospital and before they had been supplied with artificial limbs, had taught themselves, the one technical design the other ornamental design. Both of them, as soon as they were discharged, have been taken on by their former masters, who no doubt were fully conscious that they were thus combining a good deed with good business. To come to a decision of any value, however, cases of this sort must not be taken as a criterion, for they are in fact exceptional. The majority of the men are in need of guidance.

The procedure employed at the Belgian centre of re-education at Port-Villerz consists in allowing

the patient to frequent the workshops at will for a few days, during which time he sees what is going on and is not slow to make his choice, which it appears rarely needs to be amended.

We have dealt chiefly with the conditions which are suitable for the re-education of a man who has lost an upper limb, or, speaking more generally, is disabled in one arm, for whom resumption of work in a workshop will often be out of the question. The question is easier of solution for the lower limb. Cases of amputation of the leg can work standing, if supplied with an artificial limb, at practically any trade. Cases of amputation of the thigh have numerous manual occupations open to them in which they sit for at least part of the time. It must be understood, however, that these professions which require skill can, as a rule, only be learnt in well-equipped workshops at the price of a fairly long apprenticeship. Two or three years are necessary to make a good mechanic, a good watchmaker, glass-cutter, etc. This should not deter us in the case of fairly young men. The difficulty is to organise special workshops, often with a complicated equipment, where the maimed man can at least pick up the rudiments of the work, for it is not to be thought of that he can remain there during the whole time occupied in a complete training.

In conclusion, we should like to draw attention to the law of 1831, which regulates the distribution of pensions by means of groups classified according as the loss is of two limbs or of one. No distinction is made with regard to the seat of the amputation. But a man who has lost both legs and has been suitably equipped with artificial limbs can earn a fair wage,

whereas a man who has lost both arms is completely disabled so that he cannot even wash or dress himself. Among the amputation cases the difference is also considerable in the lower limb, between amputation through the leg and through the thigh, and even more in the upper limb, between an amputation retaining the movements of the elbow and one in which they are lost. There is, moreover, a great difference in the quality of stumps and the consequent utility of the artificial limb. It is of course impossible to allow with mathematical precision for all degrees of disablement, but the several general distinctions which we have enumerated could be taken into consideration without difficulty.

SECTION III

AFTER EFFECTS OF WOUNDS OF THE BONES AND JOINTS

The After-Effects of Wounds involving Bones and Joints

CHAPTER I

DEFECTS OF BONY UNION

Cases of defective union and mal-union in bones are among the frequent after-effects of gunshot fractures. Loss of bony substance of immediate or later occurrence, wounds of the soft parts preventing the methodical application of requisite apparatus, infection of the bone of a more or less chronic nature, are among the causes of the frequency with which are observed :—

1. Mal-union, the result of overlapping or angulation of fragments.
2. The excessive production of callus.
3. Delay and absence of union.

I shall not deal at length with these different lesions, because they have but little special significance in the surgery of war. There is, however, one peculiarity that I wish to emphasise, and that I shall refer to again and again without fear of repetition, *i.e.* the frequent recrudescence—spontaneous or excited by unwise interference—of the primary infection in wounds that have been healed for a long time, and to all appearances finally.

1. Shortening and Angulation of Fragments

Fractures, wherever they occur, become consolidated—

(1) By means of a cylindrical sheath of sub-periosteal bone, rapidly formed, and destined eventually to be partially or wholly reabsorbed. This is the "Provisional Callus of Dupuytren." (2) By the intermediate callus, which is lasting, and becomes organised gradually beneath the support of the sub-periosteal callus.

These two formations vary in their importance and persistence, according as the fracture is in a good or bad position, or is infected or uninfected.

Let us take as the first point of comparison the case of a simple fracture without any displacement, or with fully corrected displacement. The sub-periosteal sheath of small volume is reabsorbed rapidly, and only the intermediate callus persists. The bone attains, almost without perceptible difference, its former shape, length, and structure. When the reduction is imperfect it is, on the other hand, the sub-periosteal callus which becomes the more important, at times very markedly so. Indeed, if the displacement persists, the detached periosteal laminæ undergo an intense ossification so as to make up what is lacking in the attempt at union of the badly displaced fragments.

In the case of a simple lateral displacement, fig. 2 shows how the periosteal callus firmly re-establishes the continuity of the bony lever; this then becomes modelled, but only to a slight extent reabsorbed; the consolidated bone remains with more or less sharp angulation and thickened, but without shortening.

The method is the same if overlapping exists, *i.e.* elevation of the lower fragment alongside the upper, to which it remains parallel (fig. 3). But the frac-

FIG. 1.—Sub-periosteal callus in a fractured femur (child) without displacement, and of one month's standing; the space between the fragments is well shown.

FIG. 2.—Callus produced from the periosteum which has been stripped in the direction of the displacement; fracture with complete transverse displacement but without overlapping of the fragments.

tured surfaces here have lost all contact. Only the denuded surfaces of the shaft touch each other, without, however, giving support to the axis of the

limb; hence the intermediate callus is slow in formation, and very slow in reaching strength sufficient to withstand pressure in the long axis of the limb; the callus is exuberant—it may end by being double the thickness of the former bone—for a long time, if not for good; it is chiefly sub-periosteal, and shortening is inevitable (fig. 4).

Fig. 3.

Fig. 4.

Fig. 3.—Fracture with transverse displacement and overlapping of fragments. The callus has been produced by the periosteum, which has been stripped from the shaft on one side only (fig. 4).

In these cases, despite the slight degree of calcification that the relative transparence of the callus indicates, union was sufficiently firm to allow of walking.

By angulation of fragments the direct transmission of pressure from one fractured surface to the other is still more interfered with. The principal rôle is played, both originally and ultimately, by the mass of sub-periosteal bone which grows in the area of the angle formed by the two fragments; the bone, when finally united, remains crooked, the seat of union is always considerably thickened, and shortening of the limb is inevitable (fig. 5).

These two displacements are frequent, and it should be recognised that this fact has a direct bearing on the problems of treatment. It is certain, however,

FIG. 5.—Union with marked displacement and angulation of the fragments of the femur.

that they are often inevitable, the severity of the immediate infection and the extent and position of the wounds having made the proper application of splints difficult, both in the early and in the later stages of treatment.

I do not insist further on these causes, a study of

early complications not lying within the limits of this book, in which I have to deal only with lesions which are already long established and chronic.

FIG. 6.—Fracture of the femur, with shortening due to neither angulation nor overlapping, but to actual loss of substance. The bullet has been broken up into fragments.

In war surgery, especially in the case of the femur, whatever care may have been expended in the mechanical treatment of the fracture, real shortening, not due to overlapping or angulation, occurs with peculiar frequency. We can do nothing in fact for the often considerable space left by a loss of bony substance (fig. 6).

If, by continuous extension, we lessen the shortening, if, while waiting, as I will describe, for the removal of sequestra we maintain the length consonant with the periosteal sheath during its process of ossification, it will be none the less true that in many cases union cannot occur without a considerable elevation of the lower fragments towards the upper. Under these conditions it is the rule, almost without exception, that osteomyelitis (acute, and later chronic) constitutes the most important factor in the problem of treatment. A similar loss of substance in one of the two bones of the forearm or leg will result, almost inevitably, in a pseudarthrosis.

In the forearm union in a bad position with the lower fragment in pronation and the upper in supination is very common. It is a lesion well known in civil surgery, and one that is very disabling from a functional point of view, for it limits more or less, sometimes to complete suppression, the movement of supination. It is well to repeat as often as the opportunity occurs that this is the almost inevitable consequence of treating a complete fracture of the forearm by immobilisation in semi-pronation, as certain writers have advised. The only method to be recommended is immobilisation of the forearm in supination. In war surgery inflammatory complications often prevent us from so doing, but whenever possible this should be our aim.

Mention should be made of ankylosis of a pair of bones together. This is a lesion of no importance in the leg but very disabling in the forearm, where it puts a definite obstacle in the way of movements of pronation and supination (fig. 7).

The surgical methods that should be employed in

these cases depend on the functional troubles resulting from these defects of union.

In the upper extremity shortening of the humerus results in but little functional inconvenience, and no treatment is required. In the lower limb, on the contrary, a shortening which exceeds 3–4 cm. is disabling, and cases occur with 10–15 cm. shortening or more. For the shortening due to loss of substance in the length of the bone the only resource is a surgical boot with thickened sole. In spite of the obstinacy of orthopædic instrument-makers, our aim should

Fig. 7.—Fracture of both bones of the forearm united in pronation, and with synostosis of the radius and ulna and sequestra. Wounded 26th January 1915; date of radiogram, 17th February 1916.

be for the patient to walk as much as possible on the flat of the sole. Of course the boot looks less inelegant if the heel alone be raised and the patient walk in equinus. But in this case the toes press with their tips against the toecap of the boot, become crowded together, and bear fatigue very badly. Where the shortening is considerable we are obliged to allow a certain obliquity to the sole, but we should always be careful to make this as little as possible in order to avoid the slipping forward of the foot.

Since the war there has come into use an arrangement which allows an independent thick cork sole to be fitted on to any shoe; hence a remarkable economy,

since with a single cork sole one can wear out several cheap shoes, orthopædic boots—properly so called—which require frequent repairing, being always expensive.

For cases of union with overlapping and angulation of the fragments, especially of the femur, osteotomy followed by reduction and fixation in good position with continuous extension is generally indicated. Excellent results are obtained, much better than by osteoclasis, which, moreover, is useless in cases of union with overlapping. The same applies to radio-ulnar synostosis; osteotomy alone can correct this deformity.

But here in war surgery a new and special factor comes into play.

In general, in civil surgery, we may say that compound fractures are, so far as orthopædic operations are concerned, almost identical with simple fractures; suppuration has usually been only moderate; the callus hardens fairly quickly and certainly after the removal of sequestra, if this has been necessary, and after waiting some months there is little liability to a recrudescence of infection.

In war surgery, however, such recrudescence is more much frequent and much more formidable. Hence orthopædic osteotomy will have to be performed late, and we should abstain from operating on cases where the deformity is only slight, but in which, under other circumstances, an operation would certainly have been indicated. This is, moreover, a fact which should be kept in mind in connection with all orthopædic operations necessitated by deformities the result of wounds in war.

In spite of this, I believe that, as a general precept,

osteotomy is better than osteoclasis. It has not been proved that recrudescence of microbic activity is less to be feared after a subcutaneous fracture, and in these bones, irregular both in shape and consistence, it would probably be impossible to perform osteoclasis with any degree of precision.

2. Excessive Formation of Callus

An excessive amount of callus is due to two causes: (1) imperfect reduction with overlapping of fragments, (2) excessive sub-periosteal osteogenesis.

This second cause has a maximum effect when the periosteum is infected, or at least abnormally irritated, even if infection itself is not apparent—which does not mean, however, that it may not really be present.

We see examples of this phenomenon, whatever some may say about it, in a number of simple fractures treated by open operation, with sutures, clamps and plates of various shapes and sorts. When, some time after the operation, successive X-ray plates of such cases are carefully examined, it is evident that the volume of sub-periosteal callus is abnormally great, and that it often keeps growing, little by little, for several months. This callus again remains tender to pressure, and even really painful; it has a tendency to undergo rarefaction around the foreign body that is keeping up the irritation, and secondary elimination after late suppuration is not uncommon, whilst surgical removal undertaken to relieve pain and persistent inflammation is at times necessary.

If this is the case with foreign bodies of surgical origin, whose asepsis is not always absolutely beyond

suspicion, although at first apparently sufficient, it

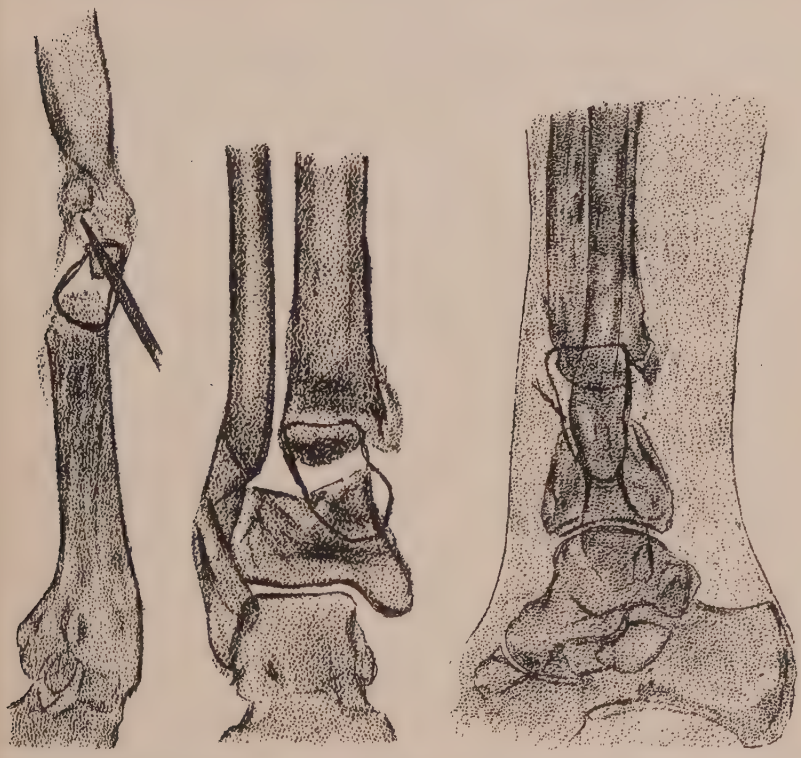


Fig. 8.—Pseudarthrosis of the humerus in a man of thirty-four, showing the existence of a ring-shaped sequestrum of the upper fragment (transfixed by a grooved probe) perforated by a silver wire which is keeping up rarefying osteitis in the lower fragment. Patient was wounded by a piece of shell, 2nd November 1914. The radiogram taken 21st January 1916. On 23rd January 1916 the wire and sequestrum were removed and the surface of the lower fragment freshened; the wound healed, but the pseudarthrosis remained, 19th May 1916.

Figs. 9 and 10.—Antero-posterior and lateral views of a pseudarthrosis of the tibia in a man of twenty-three, wounded 26th April 1915; wiring of the bone (20th September 1915) failed—caries of both fragments and a sinus being kept up by the presence of the wire. Removal of the wire, 23rd February 1916; wound healed 1st May 1916.

will be readily understood that when, in war surgery,

foreign bodies remain embedded in bone the effect is bad even if primary suppuration has been absent, or only slight and of short duration.

This is frequently the case in certain fractures in which the covering of the bullet has been torn, and in which the lead has broken up into small pieces on striking the bone. (See fig. 6. The large foreign body is the hard covering of a bullet.) In such cases the callus produced remains for a long time hot and painful, and is only slowly absorbed and remodelled, specially if irritated by massage or untimely mobilisation.

The same thing happens, with more certainty, in the case of foreign bodies which are clearly infected, and it is on this account that, in my opinion, the various osteosynthetic operations are but rarely indicated in the immediate treatment of gunshot fractures. For the most part these pieces of metal are badly tolerated, they keep sinuses open, cause necrosis, and—more often than is usually thought—result in non-union. I shall have to return to this subject later.

Speaking generally, excessive formation of callus occurs in infected fractures, especially in those in which sinuses remain open. The second part of this book is devoted to the consideration of these.

Even in cases which are not or are no longer fistulous, excessive callus is often the result of an infection, which is latent for the time being, but susceptible for an indefinite period of giving rise to a more or less acute exacerbation of inflammation—either spontaneously, or as the result of interference.

For the moment excessive callus concerns us inasmuch as it interferes with the function of neighbour-

ing structures, which are displaced, compressed, or involved by it.

In the neighbourhood of a joint it limits the normal range of movement: we will discuss this in connection with ankylosis of joints.

Muscles, tendons, and vessels nearly always accommodate themselves fairly quickly and well to changes of relation and direction in this way imposed upon them. To liberate by operation adherent tendons seems to me to be but rarely indicated. On the other hand, the involvement of nerves which are enclosed, irritated, or stretched by callus is fairly frequent, and forms a clear indication for operation.

Excess of callus in such cases is usually but not invariably present; it does not, moreover, change the surgical indications at all, and only affects the technique of the operation to a slight extent. This consists in finding the nerve as near as possible to its point of entrance into the callus, but where it will certainly be free from it; with chisel and mallet the nerve is then followed through the bone, in which a groove is cut along its course.

To understand properly the connection of certain nerves and certain bones is merely a matter of anatomy —*e.g.* the circumflex nerve winding round the neck of the humerus (its involvement is rare), the external popliteal around the neck of the fibula (involvement infrequent), the musculo-spiral around the middle of the humerus (involvement frequent).

The incision by which the bone is approached—most often the humerus in cases of musculo-spiral involvement—is the same as that for suture of the nerve or for freeing it from scar tissue. The only difference in the operation is that in the present case

an uninterrupted nerve-trunk is found which requires no suturing, but which does require to be protected, just as if it had been sutured, against any renewal of compression or involvement, the best method being, in my opinion, to encircle it with a flap of muscle taken from the triceps in order to remove all direct contact between nerve and bone.

The practical differentiation of the two conditions, solution of continuity requiring suture and compression requiring liberation, is, however, a matter of the greatest importance for the surgeon.

If division of the nerve is diagnosed, suture has a chance of success only when healing by first intention (I mean of the operation wound, and not of the nerve itself) is assured. The operation will therefore only be carried out when the fracture is united, and when suppuration has ceased for several weeks; of course the operation must not be too long delayed, but, in order to ensure success, early operation is to be considered a matter of the second and not of the first order of importance. Whether the division of the nerve has lasted a second or a year, the processes of degeneration in the lower portion and subsequent regeneration from the upper remain the same. There are of course many obvious reasons for operation without unnecessary delay so as to avoid as far as possible certain secondary lesions in the muscles and joints, but the chief concern is that the sutured nerve does not suppurate. I do not insist further on this point, which will be treated in a special volume.

If, on the other hand, compression or irritation of the nerve is diagnosed, it is necessary to operate at once, for ascending neuritis commences and increases quickly, and the nerve fibres must not be allowed

time to undergo further degeneration. Operation should be immediate even if the fracture is still septic, and even if it is not certain that definite sequestra have as yet been formed.

When removing sequestra or operating on a bony cavity, if a divided nerve is found the correct course is certainly to suture it, for very often it can be isolated sufficiently from the seat of suppuration; but this will be only an accessory to the main operation, that is to say, an exploration of the nerve would not have been undertaken if it had not been necessary to operate upon the fracture. This applies also to early operations on suppurating compound fractures.

The diagnosis between anatomical division and compression by callus is in theory very easy. The paralysis is immediate, sudden, and complete in the former case; late, progressive, accompanied by neuralgic pains, often with retention, at least partial, of some forms of sensibility, in the latter.

In the case of a patient who soon after being wounded has come under the care of an observant surgeon in a hospital where there has been sufficient time and opportunity for a complete and thorough examination, this differentiation becomes subsequently a simple matter But often at the base we receive wounded after several weeks or months, bearing labels on which the information is insufficient. This is inevitable on the evacuation labels from the field-dressing stations. In action there is no time to devote to detailed observations (which are, moreover, of little use), much less to write them on the label. It could, I believe, be avoided in the notes of a regular hospital. But I have had to regret, even from these, the frequent absence of any accurate

notes. We are, then, often reduced to accepting the word of the patient, who has not always had the presence of mind to notice whether, at the time of the accident, a drop wrist or foot complicated the general uselessness of the limb, and once splints have been applied, has been no longer in a position to take notice of these points.

3. False Joints and Loss of Bony Substance

(1) Varieties of False Joints

Before studying the treatment of false joints, it is necessary to distinguish with care the varieties of delay in union.

The average time necessary for the consolidation of a simple fracture in good position in a young and healthy adult varies, according to the size of the bone, from one month in the case of a bone of the forearm to two months in the case of the femur. This period is lengthened (1) when reduction has been imperfect and the periosteum almost alone contributes to the formation of the permanent callus, (2) when the fracture is comminuted. It is an especially long period in cases of compound suppurating comminuted fractures, and in war surgery we have often to count on a fracture of the femur with or without a sinus taking from four to five months to become firm. A period longer than this constitutes a definite delay in union.

In theory, the difference between delay in union and a false joint is clear. Whatever time has elapsed, delay in union is characterised by persistence of the osteogenetic process; a false joint by the final arrest of this process between the two fragments, each of which has undergone separate cicatrisation. In prac-

tice, the diagnosis between the two conditions is not always easy. The time that has elapsed, as I have just said, is not the criterion; a simple fracture with an interposition of muscle becomes, so to speak, immediately an example of a false joint. On the other hand, certain fractures ultimately unite without any special surgical treatment at the end of a year or an even longer period. This remark applies especially to cases where irritation of the seat of fracture is kept up, suppuration having ceased, by the existence of a foreign body in the bone, whether it be a projectile, wire, a metal suture peg, or plate of surgical origin. One must judge of the question by radiography.

When the fractured bone remains flexible, if there is still a persistent sinus we should always admit in principle that it is a case of delayed union, and, after radiographic verification, extract the sequestra and excavate the diseased area. Very numerous are the cases in which, after several months of suppuration, clearing out the infected area of the bone, specially if there have been sequestra, leads to a rapid return of the process of ossification, which previously had come to an almost complete standstill. In operating for chronic osteomyelitis I have several times noticed that in the middle of the sub-periosteal hyperostosis the fragments of the diaphysis were united only by dense fibrous tissue, which later has undergone ossification.

Palpation of the site of fracture supplemented by radiographic examination enables us to form a fairly correct clinical conclusion.

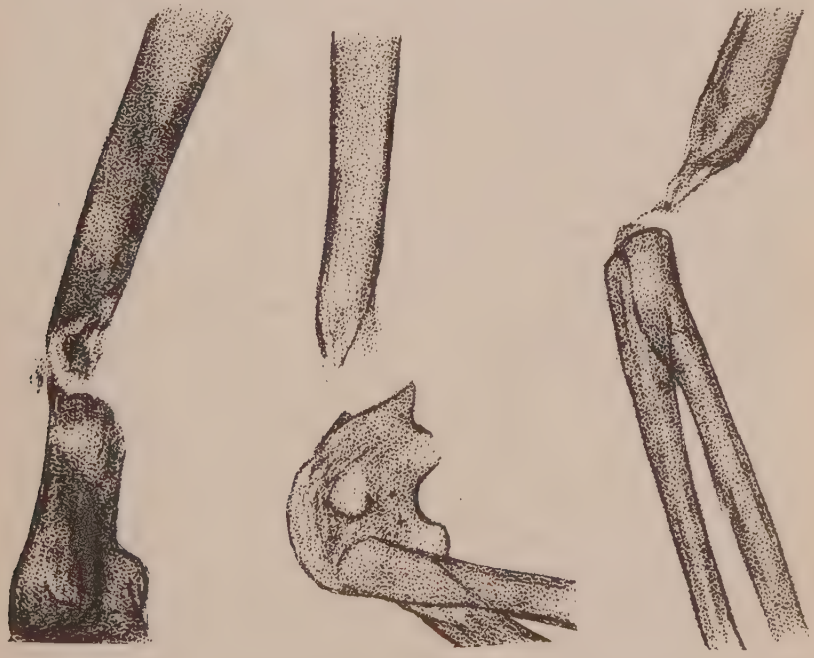
The principal characteristics of a real false joint are considerable abnormal flexibility, absence of pain on movement and pressure, and absence of tension

and œdema in the soft parts that are more or less adherent to the seat of fracture. If the bone ends are still enlarged and the soft parts infiltrated with œdema, if the bones are only a short distance apart and the amount of abnormal mobility slight, if movement causes pain and even light pressure is painful, then one may safely conclude that there is merely delay in union, in which there is no indication for a hasty operation.

In these cases radiography gives useful information, but one must be able to appreciate the exact significance of the various details. In the first place, it should be remembered that callus, especially intermediate callus, often casts no shadow on a X-ray plate for a considerable time, even though clinically the union of the bone seems complete (see fig. 1); again, it is often impossible to diagnose by examination of the negative cases in which the callus is still but poorly ossified; and when on manual examination we no longer find abnormal flexibility or tenderness, that does not mean that in the lower limb we may not be surprised by late angulation from bending of the callus under the body weight. The common fracture of Dupuytren long ago taught us the necessity of forbidding early weight-bearing when we suspect but slow ossification of callus.

When all suppuration has ceased and abnormal mobility still remains, radiography permits us to establish one of two points: the presence of a considerable bony loss, the end of the fragments being far apart, or else the presence around the seat of fracture of a greyish shadow with indefinite edges, a sign of very slow calcification of callus. In this latter case the value of successive radiographs at

monthly intervals in order to follow by the increasing opacity of the shadow the progress of ossification will at once be obvious; even where there is considerable loss of substance of the shaft, regeneration of bone from the sheath of surrounding periosteum



FIGS. 11–13.—Three examples of pseudarthrosis of the humerus; occurring in the middle of the shaft (fig. 11), in the lower part of the shaft with ankylosis of the elbow joint (fig. 12), the articular variety (fig. 13). In the last probably also the olecranon of the ulna has been resected. All three resulted in flail limbs, and in all were present sinuses which soon healed after the removal of small sequestra (fig. 11), or after excavation of a focus of caries (fig. 13).

is not at all exceptional if one only has the patience to wait for it.

In the typical plate of a true false joint the shadow of the fragments should appear opaque and of a regular or irregular shape, but with very clearly marked definite

margins like that of the bone of a completely healed amputation stump.

In war surgery the usual cause of a false joint in the shaft of a bone is this loss of too great an extent of bony substance, the result depending on whether there exists but one bone in the limb segment (arm and thigh) or two bones (forearm and leg). In the former case, elevation of the lower fragment often allows consolidation to take place at the expense of considerable shortening. In my experience, pseudarthrosis in the shaft of the femur is rare; in the humerus, it is rather more common.

Where there are two companion bones in the limb segment, if one has escaped fracture, or if fractured has united without or with but little shortening, it places a very definite obstacle in the way of approximation and union of the two fractured ends of the second bone. This condition of affairs occurs sometimes in the leg, more often in the forearm. Pseudarthrosis occurring simultaneously in both of the bones of these segments is very rare.

A special form, " articular " false joint, occurs when the loss of substance involves an epiphysis in the neighbourhood of a joint as well as the neighbouring part of the shaft, and when the wound has healed without ankylosis of the joint, which becomes flail. I have not seen examples of it in the ankle and knee joints, probably because fractures which would lead to this result have been such as to necessitate immediate or secondary amputation. This form of false joint, however, sometimes follows a resection of the hip, which has succeeded in saving the life of the wounded man, but which has resulted in a limb of but moderate utility, although infinitely superior to

an artificial limb fitted to the pelvis after a disarticulation at the hip joint.

The usual position, however, for an articular false joint is in the upper limb, sometimes at the wrist joint from loss of the lower end of the radius, more often at the elbow and shoulder from loss of the corresponding epiphyses of the humerus.

The regular pathological type of false joint is that of fibrous union, the tapering bone ends being joined together by bands of fibrous tissue; close fibrous union, rather rare, when the bone surfaces remain in contact, and when, if there is no interposed muscle, a late, slow ossification may for a long time be hoped for; and flail fibrous union, more common when a considerable length of fibrous tissue replaces the lost bone. I have not seen cases of real "false joint," that exceptional form with fibrous ligaments and synovial lining.

(2) Treatment of Non-union.

It is necessary carefully to distinguish between the treatment of mere delayed union and that of true pseudarthrosis.

A. *Delayed Union*

I have already explained the rôle played in this by sequestra and foreign bodies, and the necessity for their removal.

In cases where neither of these two causes of delayed union exists, where suppuration has ceased, and there is no foreign body, and where on the removal of splints after the usual period abnormal mobility is found to exist, the difficult problem arises whether to persist in immobilisation or to leave the limb more or less unrestricted in its movements.

There are of course cases of delayed union—often wrongly described as false joints—in which, after a delay of some months, new bone formation has been stimulated by some purposive form of irritation of the seat of fracture—*e.g.* the old methods of treatment, forcible rubbing together of the fractured end, injection of mild chemical irritants, and acupuncture.

These various procedures are probably no more efficacious than permitting slight movement at the seat of fracture, the limb being either left free of all apparatus and lightly massaged, or else put up so that the movements of the neighbouring joints which are left unrestrained by apparatus cause a certain restricted amount of movement at the seat of fracture itself. A little movement is allowed, but only a little.

As a general rule, this latter procedure seems to be preferable either to absolute immobilisation or to leaving the limb quite free. We should try it for successive periods of three to four weeks, noting at each change of apparatus whether the mobility appears less, and whether radiographs show an increase of ossification in the callus.

For this purpose the extension apparatus of Delbet for the humerus and femur, and his plaster splints, which allow the patient full use of the limb in fractures of the tibia and fibula, are most excellent. I am accustomed to apply these as soon as the pathological state of the parts allows of it, and to continue them as long as one is certain that a false joint does not exist.

If the delay in union is prolonged, particularly in the lower limb, and above all in the leg, it is easy to substitute for these heavy splints orthopædic appa-

ratus similar to that prescribed for inoperable false joints, or for those in which operation has failed. This method of treatment avoids two very common practices which are to be condemned, viz. in the case of the upper limb, keeping the arm in a sling; in the case of the lower, giving the patient a pair of crutches.

Patient and careful observation is necessary before finally concluding that the process of consolidation has definitely come to an end.

B. *False Joints*

The means of treatment at our disposal are :—

1. An open operation with the object of obtaining bony union.

2. The wearing of an orthopædic apparatus.

The principles of the orthopædic apparatus vary with the different segments of the two limbs; those of surgical operations are, however, general and constant.

(a) *If the fragments are in contact without loss of substance*, the old method of freshening the bone ends should first be tried. The seat of fracture is opened up, the periosteum preserved with the greatest care, intermediate fibrous tissue excised, and the ends of the bone freshened either with the curette or the saw, with the object of obtaining close contact between healthy, well-vascularised bony surfaces. By doing this there necessarily results a certain amount of shortening, usually of no importance in the case of the humerus, and even of the femur—where, however, pseudarthrosis rarely occurs—but incompatible with accurate coaptation of the cut surfaces in those segments of the limbs where there are two bones and

the other is sound. If the separation of the surfaces is not great, this difficulty may be overcome by resecting a short segment of the normal bone; if the separation is considerable, we must have recourse to a bone graft.

Fig. 14.—Osteitis kept up by an attempt at wiring for non-union.

After freshening the ends most surgeons assure the maintenance of the freshened surface in good and close apposition either by suture of the bones or by one of the methods by which this has been replaced and simplified in recent years (metal plates or staples), or else by an intramedullary peg of ivory.

I believe that there is a tendency to abuse the insertion of these foreign bodies in bone. Even when the seat of the fracture has throughout been closed and aseptic they irritate the bone, cause rarefaction, and provoke the formation of callus, which is exuberant but at the same time insecure. Secondary sinuses are far from being exceptional. Moreover, it is often possible without these to maintain good position by means of well-fitting external splints; but when this latter course is impossible, it is, in my opinion, better deliberately to remove the foreign body as soon as the callus has commenced ossification. Consequently I prefer fixation with wire, or, better still, with a staple, to the use of intramedullary pegs (fig. 14).

(b) *If there is such loss of bone* (either originally or

as a result of removal by operation) as is incompatible with coaptation of the fragments, we must have recourse to bone grafting.

Sometimes it is possible to insert into the gap a bony fragment with an adherent pedicle taken either from the bone itself or from a neighbouring bone. I shall describe this in connection with losses of substance of the tibia repaired from the fibula (see p 575).

Most often a separate fragment is taken from a distance :—

Either from the patient himself, *autoplastic graft* ;

From an animal of the same species, *homoplastic graft* ;

From an animal of a different species, *heteroplastic graft.*

It is generally recognised that success is more likely if the graft retains its own periosteal layer, but this is not indispensable.

In the case of a pseudarthrosis a graft of large size must be used, and most often an attempt is made to introduce its two ends into the medullary cavity of the existing fragments.

From the study of experimental grafts in animals, and from their use in man in an aseptic field of operation, it has been found necessary to discriminate between two things, the " taking " of the graft and its ultimate fate.

I shall not consider cases where suppuration occurs and the graft comes away ; the first condition of success is primary union of the operation wound. Further, it must be understood that antiseptics must not be used ; they adversely affect the vitality of the cells.

In an aseptic case the graft usually " takes," even

when it has been heteroplastic. In man, radiography has shown the bony fragment surrounded by callus; in animals, its survival and vascularisation have been established by post-mortem examination. The frequency of this immediate success should not, however, be exaggerated. More often than could be wished it is only partial: the fragment survives, but remains free at one end, sometimes even at both ends, and consequently consolidation is not obtained.

Even in cases that for weeks keep up a promise of ultimate success, one is liable finally to fail owing to a late but progressive absorption of the graft.

The present consensus of opinion is that even with an autoplastic graft this absorption is constant, or almost constant. The graft plays its part merely by exciting and directing an osteogenesis by substitution. This is a source of discussion of great scientific interest, but of no very great practical importance. If secondary ossification of the graft has occurred, it matters little whether the ultimate callus is formed by the transplanted bone itself or by new bone which has gradually replaced it, so long as in the end the continuity of the bony lever is re-established.

But if absorption takes place quickly substitution has not time to occur, and the final result is failure. Occurring in all three varieties of grafts, this excessively rapid absorption occurs in an increasing order of frequency with autoplastic, homoplastic, and heteroplastic grafts. Further, it may be said that the heteroplastic graft, the taking of which is more dependant on chance, and the absorption of which is more frequent, has not up to the present progressed beyond the experimental stage, despite a few fortunate successes, of which there are even some in classical

surgery. This is a pity, because they constitute the most convenient method of obtaining at any time a massive graft.

An opportunity for the use of homoplastic grafts but rarely presents itself, and even when it does there is always the fear, despite all clinical and laboratory precautions, of inoculating the recipient of the graft with tuberculosis or syphilis.

Grafting by the autoplastic method alone is therefore carried out with any frequence, and the transplanted pieces are almost always taken either from the fibula (the whole middle third of the shaft of which can be resected without leaving functional disability), or from the tibia, whence a sufficiently long piece can be taken without difficulty from the crest.

Indications.—What I have said as to the absolute necessity for primary union after bone grafting, and its almost equal necessity after simple freshening operations with or without bone fixation, indicates that in war surgery the frequent recrudescence after open operations of infection, over which we have no control, forms a great stumbling-block in the way of success. It is advisable, therefore, to wait a very considerable time before operating; all vascularity should have disappeared from the scar, and the neighbouring tissues should be quite supple, and even then there is no absolute assurance of success.

Even if the wound does not suppurate, failure to secure union is not at all rare.

In spite, then, of the incontestable progress of the last thirty years, the treatment of "false joints" by open operation remains uncertain. This is, however, no reason for refusing to consider operation as formally indicated if the functional disability is

serious—as is usually the case—even if in case of failure one has to fall back on an orthopædic apparatus: nothing is risked, and the gain may be considerable.

Fig. 15.

Fig. 16.

I will now enumerate bone by bone the chief functional troubles which constitute indications for treatment.

In the case of the humerus, whether it be in the shaft itself, at the shoulder, or at the elbow, the type is that of a loose pseudarthrosis. This does not mean that the limb is useless. In extension the arm

hangs beside the body limp and swinging like a pendulum. But if the muscles are good—particularly the deltoid for the shoulder and the long muscles for the arm and elbow—the effect of their contraction

FIG. 17.

FIGS. 15–17.—Flail pseudarthrosis of the humerus; involving the shaft (fig. 15) and the upper articular extremity (figs. 16 and 17). In cases 15 and 16 there are present sequestra whose removal was followed by rapid healing. In case 17 a sinus was due to disease in the fractured scapula.

is to raise the lower fragment, and then by supporting it against the upper, with, sometimes, a remarkable security, to allow of fairly vigorous action of the wrist and hand, the elbow remaining flexed. In the case of a false joint in the shaft the lower fragment is held by the triceps so as to make with the upper

fragment an obtuse angle open backwards; in this position the biceps can quite adequately flex the elbow and hold it flexed. By the use of a circular armlet which leaves the elbow free, the functional utility of such a limb can be considerably increased. In order not to constrict the limb and interfere with muscular action it is best for this armlet to have a proximal attachment to a shoulder piece which is fastened round the trunk.

In pseudarthrosis of the humerus cure by open operation is most difficult to effect. When the head of the humerus has been resected with the upper part of the shaft a vigorous deltoid can raise the lower fragment directly and keep it in contact with the glenoid cavity. But in all the cases of this sort that I have seen in war surgery there has been complete atrophy of the deltoid, and if ankylosis had been effected the functional result would have been better. Hence in cases of this sort original resection of the upper end of the humerus should be performed only when, in order to save life, the choice lies between this resection and disarticulation at the shoulder joint. Conservative measures which would result in ankylosis should be abandoned only after a full realisation of these facts of the case.

In the case of the elbow adequate voluntary movement at the site of the false joint is not rare; indeed some surgeons consider the functional result better than that of ankylosis of the elbow in good position—the muscles of the forearm and hand being equally good—therefore they prefer to treat by free and early resection fractures of the lower end of the humerus, of the upper ends of the forearm bones, or of the ends of all three bones. I speak here of immediate or early

secondary and not of late orthopædic resection, which, being sub-periosteal, allows of the reconstitution and remodelling of a firmly ankylosed joint. When the fixation by the long muscles is insufficient- -when the muscles are poor, or else the loss of bone too great—

FIGS. 18 and 19.—Pseudarthrosis in the lower half of the radius (fig. 18) and of the ulna (fig. 19), in the latter bone with but little loss of substance.

the elbow should be fixed in an apparatus fitted with a ratchet, which encircles the arm and forearm, and is suspended from the shoulder in the manner already described to avoid compression of the muscles.

In connection with these fractured shoulders and elbows I draw attention to the attempts that have been made to insert under the soft parts artificial joints of ivory fixed to the neighbouring bones. I

mention these solely to show that I am not ignorant of them.

FIG. 20.—Pseudarthrosis in the middle of the shaft of the radius, with considerable loss of substance. Cavity containing sequestra in the ulna.

FIG. 21.—Loss of substance of the fibula without the occurrence of displacement of the foot (the external malleolus has escaped; ankylosis of the ankle joint).

Pseudarthrosis, even if fairly firm, of the two bones of the forearm results in a grave disability, which is sometimes complete. That of the radius alone is

almost as disabling because of the loss or limitation of the movements of pronation and supination, and because of weakness of the fingers, the hand being flexed in a bad position; when the lower radial epiphysis has disappeared the hand deviates to the outer side, supination is impossible, and weakness of grip of the fingers is very marked. Pseudarthrosis of the ulna is much less disabling, especially when it occurs in the lower half. It may even be a good thing, especially when the radius is badly united, the lower fragments being pronated, causing sometimes less complete limitation of supination.

The forearm is the region where fibrosis and destruction of muscles and tendons and nerve lesions most frequently complicate non-union of bone and increase considerably the functional disability of hand and fingers.

If an operation by freshening the ends with shortening of the second bone (if it be intact) or by bone grafting fails, a fair result is obtained by the use of a leather armlet in pseudarthrosis of the shaft. Neither operation nor orthopædic apparatus is, however, of much use in loss of the lower extremity of the radius.

In the *femur* I have as yet seen no case of non-union of the shaft among the many wounded that I have examined. I believe that simple freshening without grafting would be sufficient. In case of failure, one would apply an apparatus transmitting the weight from the tuber ischii to the foot, like the caliper used in the convalescent stage of hip disease. The same also is useful in the case of a flail hip joint after resection; after this operation, however, ankylosis is much more commonly met with.

I have seen no flail knee joint; cases where loss

of bony substance is sufficiently extensive to lead to this result are usually treated by early resection or amputation.

In the leg, pseudarthrosis without being frequent is not rare. The most striking characteristic is the lack of stability in the limb in the standing position, hence there is a very considerable difference between pseudarthrosis of the tibia and of the fibula. A loss of substance of the fibula—even when considerable—is almost always without functional importance, provided that the external malleolus and its attachments are preserved; but if this is lost, deviation of the foot into valgus as soon as it touches the ground constitutes a very serious disability. The operative indication is then to arthrodese the ankle joint at a right angle, as is done for congenital absence of the fibula. I have seen a case of considerable loss of substance, but with preservation of the malleolus and stiffness of the ankle joint—which had been kept in a good position by the surgeon—walk very well and firmly, the sole of the foot flat on the ground (fig. 21).

Pseudarthrosis of the tibia without loss of substance, or with but slight loss—2–3 cm.—may often be treated successfully by freshening combined with shortening of the fibula, or else by a bone grafting, by freshening of the two bones if the fibula also has not united. In cases of failure a walking apparatus, with support from the tuberosities of the tibia attached to the thigh, like but very much lighter than an apparatus for amputation of the leg, almost always gives a fair amount of functional use.

The most difficult cases are those in which there is such excessive loss of substance of the tibia as renders impossible any attempt to procure contact between

the two ends even after resection of the fibula. By means of a bone graft it is also impossible to reconstruct the tibia sufficiently in length and in thickness. In such conditions, sometimes callus forms spontaneously in a favourable manner, one or both ends of the tibia becoming united to the fibula, which has itself been broken but has joined, so that the fibula itself transmits the body weight; this bone is reinforced by callus—it seems to develop later little by little, and adapt itself to its new function, and the final result is often satisfactory. It is possible in some cases to imitate this natural process by surgical methods (figs. 22 to 25). Sometimes the shaft of the fibula has been implanted into the upper end of the tibia; sometimes, on the contrary, into the lower end of the tibia; sometimes, by two operations, both ends of the fibula have been implanted in turn, so as to substitute one entire shaft for the other (figs. 23 and 24). In this last case, although the absence of the middle part of the shaft of the fibula usually results in no disability, it is well to guard against the occurrence of a valgus deformity of the foot by creating a synostosis between the lower ends of the tibia and fibula.

It is more in accordance with the normal mechanics of the leg, however, if, following Curtillet, the transplant is taken not from the whole of the fibula but only from the anterior half of its thickness. This osteoplastic strip, nourished by an internal pedicle formed of musculo-periosteal insertions carefully left untouched, is passed through an opening made into the antero-external muscles of the leg, and is placed between the two ends of the tibia, freshened and shaped like a fork (fig. 25).

FIG. 22.—Simple transplantation of the upper end of the fibula into the upper fragment of the tibia.

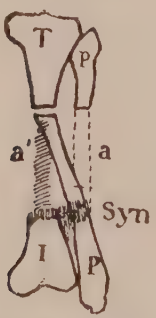


FIG. 23.—At the time of the operation.

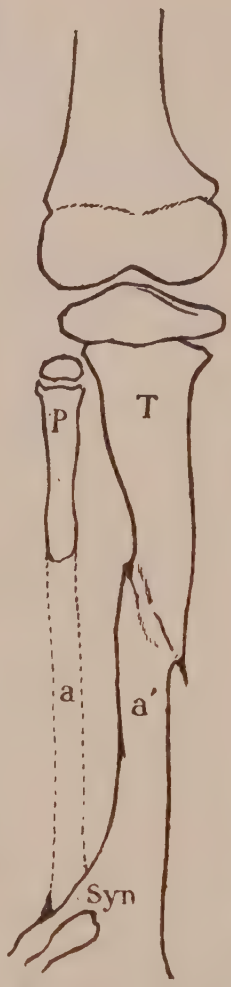


FIG. 24.—The final result.

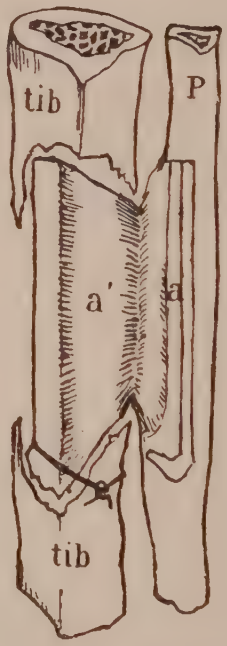


FIG. 25.—The operation of Curtillet—a fibular flap *a* is transplanted into *a'*, the gap in the tibia due to loss of bone.

FIGS. 23 and 24.—After grafting of the upper end of the fibula into the upper end of the tibia, and after the performance of arthrodesis of the inferior tibio-fibula articulation, the fibular shaft *a* replaces the tibial shaft *a'*.

After these various operations it has been frequently proved that the graft, studied by a series of radiographic plates, has rapidly grown and become an excellent tibial shaft.

Thanks to these methods, operative and instrumental, we may say that amputation is no longer indicated at the present time so far as the upper limb is concerned, and hardly ever in the case of the lower limb. It is possible, however, that in certain cases of flail pseudarthrosis of the leg this mutilation may be advisable—as in certain congenital false joints—if we consider that the apparatus will be more simple, and the support more secure with one of the excellent artificial limbs that can be made to-day for amputations in the lower part of the leg.

CHAPTER II

CHRONIC TRAUMATIC OSTEOMYELITIS

(as seen in amputation stumps and infected fractures)

1. General Consideration of Osteomyelitis

In order to understand the pathology and treatment of bony sinuses following gunshot fractures and amputations it is first necessary to grasp certain general principles of the pathology of bone inflammation.

Inflammation of bone has, as the result of conditions that it is not always easy to define clinically, two possible but opposite results, the production of new bone, and rarefaction. Proliferative or condensing osteitis (osteosclerosis) and rarefying osteitis (osteoporosis) must be studied respectively in the compact tissue of shafts of long bones (and in the compact layers of flat bones) and in the cancellous tissue of short bones and epiphyses.

Bone tissue—whether compact or cancellous—is made up of two elements, one soft, vascular and continuous, the bone-marrow, whose physiological function is to produce and then to nourish the other, which is hard and calcified and forms the rigid framework of the skeleton. It may be said gener-

ally that an inflammation of moderate intensity—for example, aseptic irritation—results in an increase in the bone-producing power of the marrow, giving rise to osteosclerosis; whilst a more severe pyogenic infection diminishes this power of the marrow, which proliferates as fleshy granulations and erodes by a process of osteoporosis the neighbouring hard parts of the bone.

In the long bones there are three parts to be considered: the periosteum, the cylinder of compact bone, and the central medullary canal.

Under the periosteum, a fibrous and practically inert membrane, lies an active layer (the osteogenetic layer of Ollier), which plays a great part in the growth in thickness of the bone. The osteogenetic activity of this layer is much the greatest in young subjects.

The compact cylinder of bone is made up of concentric layers, and is tunnelled from end to end by the straight Haversian canals in which, surrounded by cells of medullary tissue, lie the capillaries which nourish the bone. These canals anastomose among themselves by transverse branches, of which the most external open under the periosteum. Hence a continuity of blood-vessels and of marrow tissue exists between the sub-periosteal layer and the Haversian canal system. The most internal of these branches open into the medullary canal.

Now this medullary canal is really only a huge Haversian canal. It contains the bone marrow in the common sense of the term. This central marrow has normally little or no osteogenetic power. It acquires such power in certain pathological conditions, but only rarely and to a slight extent.

Let us see now how these various parts behave during osteomyelitis of the shaft of a bone.

If the periosteum has not been destroyed mechanically or by infection, its osteogenetic layer usually reacts by an exaggerated osteogenesis, hence the sub-periosteal hyperostosis which ensheaths the bone and thickens it. This hyperostosis becomes thicker as it is traced towards the actual seat of the osteitis, so that where the lesion occurs in the middle of a shaft the mass is fusiform, where at the junction of the shaft and epiphysis it tapers or is club-shaped. At the edges of the infected area, if the infection be intense, this hyperostosis is spongy in character, rarefied by the process of inflammation, but for the most part it tends to be hard like ivory.

The central marrow may exceptionally give rise to new bone. Usually it proliferates, increases in vascularity and volume at the same time as, by an enlargement of the medullary canal, the compact tissue of the diaphysis, which contains it, becomes thinned.

Caught, as it were, between the infection of the periosteum, stripped up by the suppuration and the turgid marrow which strangles the vessels in the rigid walled canals (central canal or Haversian canals), the bony cylinder of the shaft undergoes necrosis at the site of infection. This necrosis affects a very variable extent of the length and circumference of the shaft, and extends to a greater or less depth ; beyond it rarefaction occurs ; further off still, condensation.

Necrosis and rarefaction are two associated processes.

In compact tissue necrosis occurs *en masse* ; the

dead part is dense, white, and smooth; it sounds clear and dry on percussion with a probe. At first it is in actual continuity with the surrounding living tissues, just as the slough caused by a burn of the third degree is at first continuous with the sound skin. But in both cases, if there be infection, the connective tissue proliferates, becomes congested, and suppurates at the junction of the living and dead parts. At the junction of the necrosed part the Haversian canals become larger, the bone tissue becomes rarefied and then disappears, eaten away by granulation tissue. A red line of demarcation appears and gradually deepens around the white necrosed bone; thus in time the dead piece of bone is set free on all sides and to its full depth. Necrosis has thus been followed by the production of a sequestrum—free, white, and hard, but characterised on the faces and edges, that originally were adherent to the rest of the bone, by fine serrations—comparable to those hollowed out by the sea in a rocky coast.

The sequestrum would now be ready to work its way out—just as the slough of a burn falls off—if sub-periosteal ossification had not progressed simultaneously with the process of its liberation; so that it finds itself enclosed, ensheathed in a sequestral cavity formed laterally by the new periosteal bone, and above and below by the remaining parts of the former bone. This cavity, whose walls are in places hard, in others soft, is lined by soft, fleshy granulations. It contains, besides sequestra, pus, and it communicates with the outside by perforations of various sizes, in which the sinuses of the soft parts end.

In the region of the spongy bone of the epiphysis

sub-periosteal bone-formation is almost or quite absent. Here rarefaction is predominant, with proliferation of the marrow, which is sometimes purplish-red, and sometimes yellow and fatty. The bone trabeculæ for the most part disappear by progressive absorption, and in their place are hollowed out cavities filled with granulations or collections of pus. Sometimes, but rarely, a central islet dies *en masse* and constitutes a porous and light sequestrum. The process is the same in thick, short bones, especially in the tarsus. Usually the infection and rarefaction spreads to the whole spongy mass of bone. The name *caries* is given to this form of osteitis with softening of the tissue, through which the probe and curette pass as through butter. I do not think that this name, which is purely symptomatic, should be reserved for tuberculous osteitis alone.

Caries may also eat away more or less completely the compact tissue of a diaphysis.

2. Amputation Stumps that require further Operation

These general facts being known, the most simple application of them to traumatic osteomyelitis may first be studied in the bony lesions of a suppurating amputation stump.

We can easily follow the changes in the cut end of the bone with the naked eye and also radiographically.

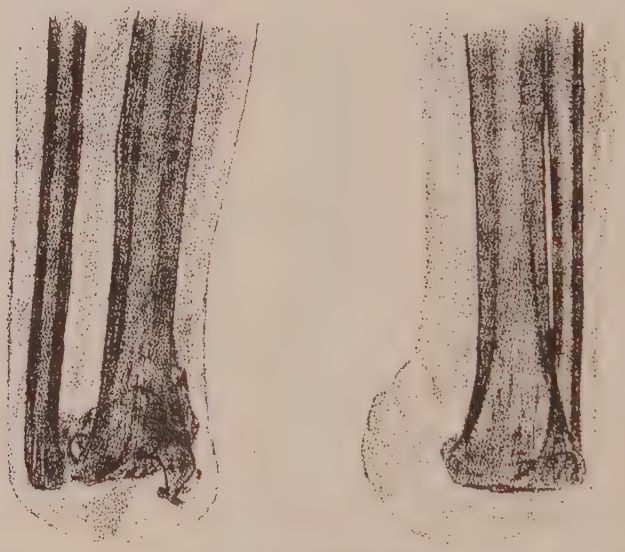
When the infection is but moderate the bone end appears white around the red and slightly projecting central marrow; then a red stippling marks in it the enlargement of the Haversian canals and the proliferation of their marrow. Very soon a carpet

of granulations covers the bone uniformly, practically no necrosis having occurred—except for such as crumbles and is thrown off almost invisibly from the bone as a sort of bone dust and is carried away in the pus. By ossification of the medullary granu-

FIG. 26.—Amputation of thigh; a good clean division of the bone which is well covered by soft parts.

lations a layer of bone is formed which obliterates the Haversian and central canals. This occlusion of the medullary canal is often one or two centimetres deep, and above it the cylindrical medullary canal ends by tapering to a point (fig. 29). The end of the bone thus becomes much more dense; further up the cylindrical shaft is normal, no sub-periosteal proliferation having taken place around it. Hence

radiography shows a bone with sharply marked edges, the cut surface smooth and free, such as that represented in fig. 26. If the soft parts around the bone are ample enough, healing occurs without complications; a scar forms which at first is adherent, but later becomes supple and movable, and ends by



FIGS. 27 and 28.—Amputation of the leg (antero-posterior and lateral views), with the formation of hard new sub-periosteal bone, causing, however, no inconvenience; bone-end quite well covered.

being practically as good as that of a stump that has not suppurated.

In certain other cases, where the inflammation has been rather more severe, the end of the bone becomes surrounded by new bone of sub-periosteal origin. In such cases the cut end of the bone is enlarged into a club-shaped mass, or presents terminal excentric projections of bone, which in a radiograph appear as a dark, dense shadow, spur-like in shape,

of varying length, and usually concave on their proximal surface (figs. 27 and 28). On examination this hypertrophy may be felt, but the bone is found to be well covered by soft parts, and not at all tender on pressure, the osteosclerosis forming in reality a good solid bony scar.

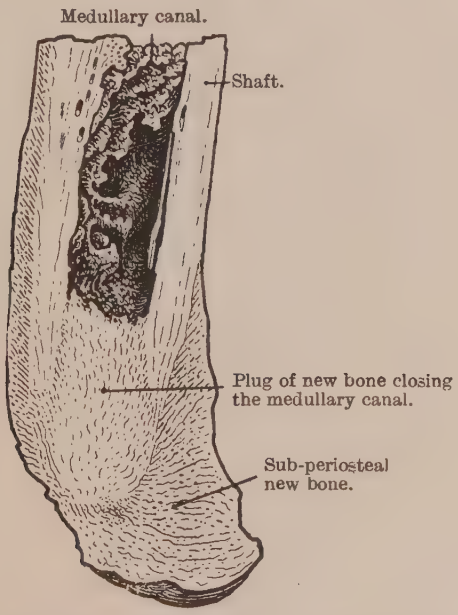


FIG. 29.—Bone-end quite soundly healed; re-amputation was necessary on account of shortness of the soft parts. During the performance of this operation one could see the original bone closed by a mass of new bone in the medullary cavity and surrounded by new sub-periosteal bone.

If the flaps of soft parts are, however, too short a thin, unsound cicatrix adheres to the end of the bone, and is often subject to recurring ulceration. If they are very short, the scar adheres like a collar around the granulating end of the bone, on to which the epithelium cannot extend—a chronic terminal

ulcer results, even though there be no underlying osteitis.

The phenomena are very different when in cases of severe infection necrosis and caries occur with

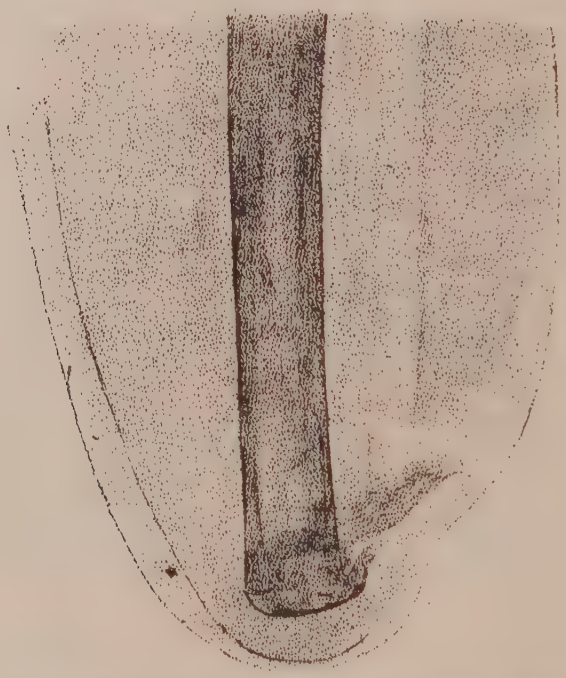


Fig. 30.—A projecting terminal spur of bone well covered.

exuberant over-production of sub-periosteal bone, which itself becomes the seat of caries.

Then a mass of purple granulations projects from the medullary canal and extends in a mushroom-like excrescence over the cut surface of the bone, which remains white until exposure to the air blackens it. The bone end undergoes necrosis for a variable length—rarely more than 3–4 centimetres—a part, or more often the whole, of its circumference being

involved. This in the end constitutes a sequestrum which usually, in from six weeks to two months, becomes free in the form of a ring, the lower edge of which—owing to the saw-cut—remains smooth and plane, whilst the upper, isolated by rarefying

FIG. 31.—A terminal spur poorly covered; terminal ulceration of the soft parts which are too short, some slight osteitis.

osteitis, is irregular and jagged, with sometimes very sharp points projecting up along the sides of the remaining part of the shaft. This upper edge is more or less overlapped by the periosteal new bone, which may even descend around and in part enclose the lower border of the sequestrum (figs. 33 to 38).

In less severe cases the new bone formed and the old shaft undergo osteosclerosis above and

around the sequestrum, the spontaneous elimination of which (or surgical removal by curetting) is sufficient to lead to the healing of the sinus. After that the nature of the stump will depend, as I have just said, on the length of the covering soft parts.

Fig. 32.—Slight amount of osteitis in a stump with a chronic sinus.

But often under these conditions the sub-periosteal bone is excessive, forming a cauliflower-like mass, which is rarefied and excavated by granulation tissue and by small suppurating cavities. In the original bone the central marrow becomes fatty, increased in amount, with a corresponding increase in diameter of the medullary cavity and thinning of the compact

cylinder of bone, which sometimes becomes reduced to a layer as thin as parchment. In extreme cases of this sort this shell of compact bone may become enlarged and distended as in a spina ventosa—a condition that may extend right up into a softened and carious epiphysis, even where the primary amputation has taken place through the middle of

FIG. 33.—A terminal ring-shaped sequestrum enclosed by sub-periosteal bone; bone-end well covered, but sinuses present.

the shaft of the bone. Such a condition is not uncommon in the upper tibial epiphysis after amputation of the leg at the seat of election (figs. 39 and 40).

Radiographically the bone appears very much enlarged, the general outlines of its shadow being opaque, but with translucent streaks and patches. Below the end of the bone often appears an irregular shadow of very variable shape, of a uniform grey colour, with no sign of any trabecular structure.

This light shadow shading off into that of the surrounding soft parts (fig. 41) has no very well-defined

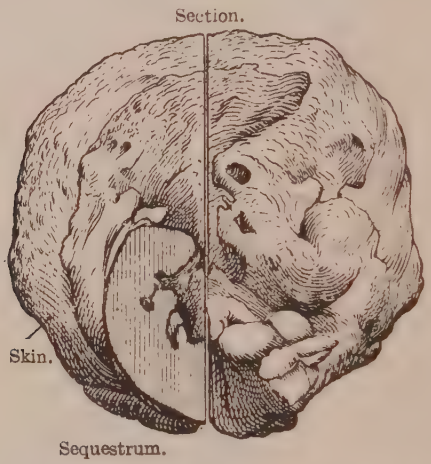


FIG. 34.—The sequestrum is seen presenting its plane surface of the original saw-cut.

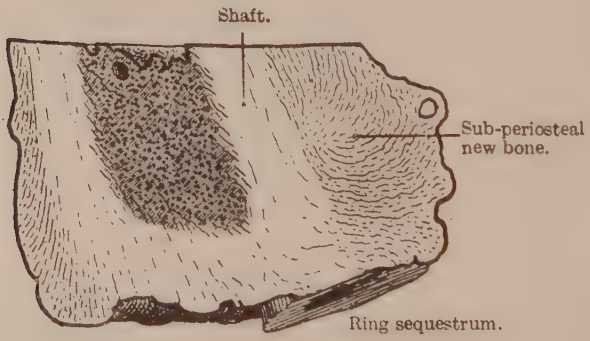


FIG. 35.—This shows the way in which the sequestrum may be surrounded by new bone. Some slight extent of osteitis present in the latter.

outline; it sometimes shows translucent patches, in which the presence of sequestra may be detected (figs. 42 and 43).

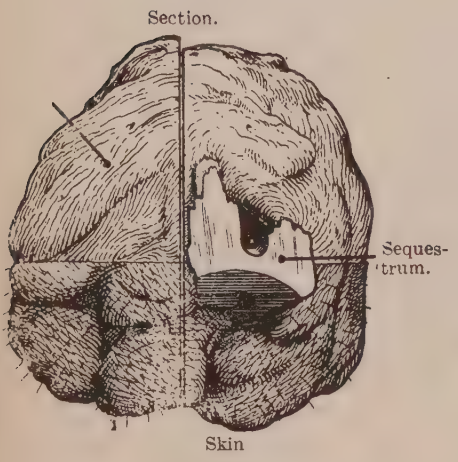


FIG. 36.

FIG. 37.

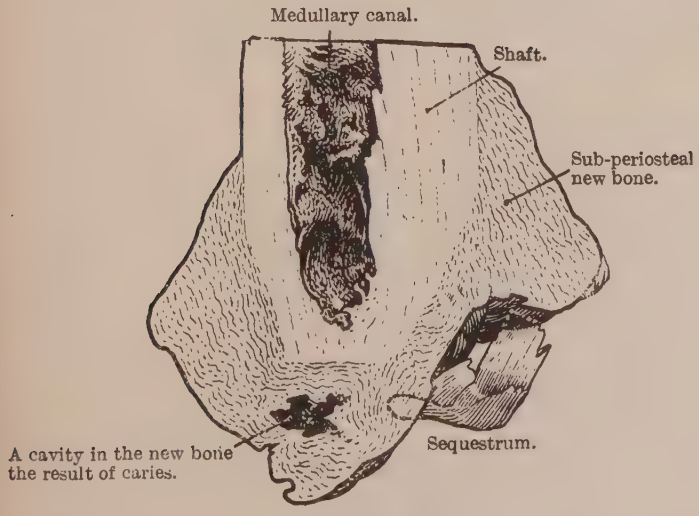


FIG. 38.

FIG. 36.—Radiographic appearance of a terminal ring-shaped sequestrum sticking out through the skin and enveloped by new subperiosteal bone (figs. 37 and 38). A slight amount of caries in the end of the bone.

FIGS. 39 and 40.—Rarefying osteitis involving the whole remaining portion of the tibia and of the radius. The bone is swollen and distended, with, however, no sub-periosteal proliferation.

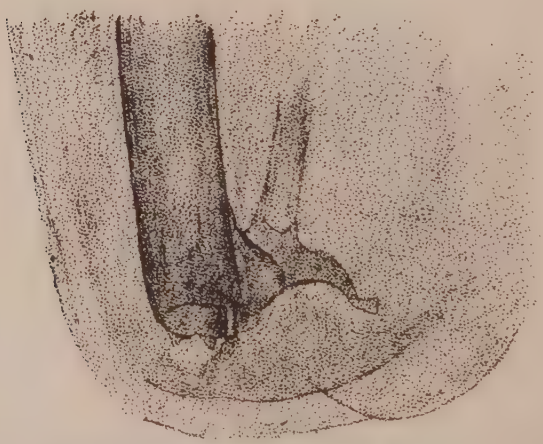


FIG. 41.—Rarefying osteitis with sinus, formation of a large terminal cauliflower-like mass of new bone.

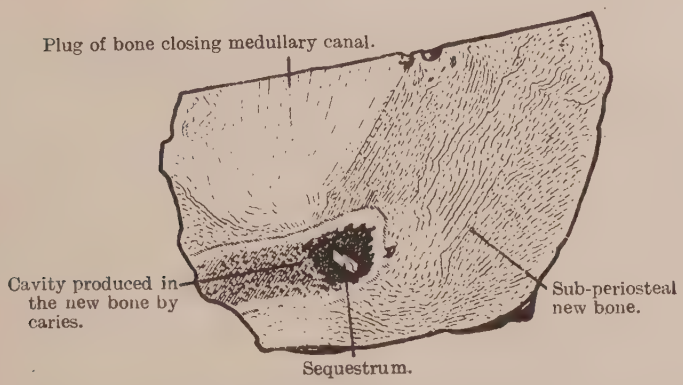


FIG. 42.—A small sequestrum of sub-periosteal bone producing an area of caries.

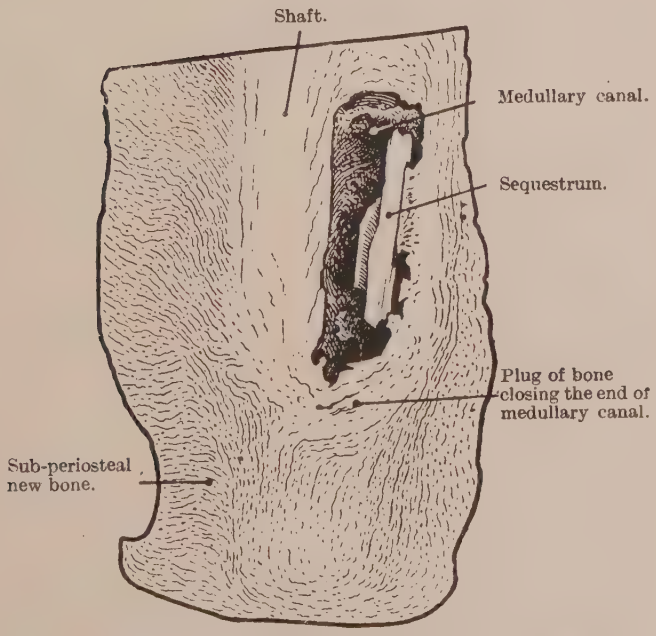


FIG. 43.—A sequestrum of compact bone, of the original shaft, lying proximal to what appears to be a soundly healed bone-end.

Such a stump is, as a whole, hard and bulky; its soft parts, often œdematous, are lacking in suppleness; below they are hard, often indurated, covered by skin in a state of chronic, even acute, inflammation. This skin, ending in a collar of fibrous tissue, becomes retracted upwards like a funnel towards the end of the bone, to which it is adherent, and connected by one or more sinuses of variable size. The bone, sensitive to pressure for a considerable distance upwards, is extremely tender at its extremity. The sinuses discharge pus, often thick, and very variable in amount. At times they almost or completely close; this leads to a reappearance of the inflammation, with redness, pain, swelling, and slight fever; an abscess forms, and the scar breaks down afresh. Or else in the seat of a former sinus there gradually forms a swelling, soft, dull red in colour, but without any marked signs of acute inflammation; in time this bursts, discharging a little turbid serum, and the sinus so formed recommences a longer or shorter period of discharge.

As long as the stump is suppurating it is of course impossible for the patient to wear an artificial limb. Even where the suppuration itself has definitely ceased, as long as the soft parts remain œdematous, adherent to bone that is itself enlarged and tender, the friction of an artificial limb will soon light up the infection afresh, and produce new abscesses and sinuses. This fact, of common knowledge to surgeons in time of peace, has often been forgotten by the neophytes in surgery that the war has produced; and I have often seen patients with amputated limbs who, fitted with an artificial limb far too soon, have had later to submit to further operations that

have so changed the shape of the stump that their former limb no longer fits sufficiently accurately. This happens especially in the case of the lower limb, where the stump must transmit body weight in the vertical plane, and where, consequently, accuracy of fit is of the greatest importance.

Such being the principal pathological and clinical varieties of infected and suppurating stumps, let us next consider what operations are necessary in order to bring about final healing, and so to prepare the stump for the reception of its artificial limb.

The simplest case is that in which the bone itself being soundly healed, the end of the stump still remains adherent, or is incompletely healed or liable to constant recurrence of ulceration, the soft parts being too short to cover and pad the bone end. This is the chief defect of circular amputations in which suppuration has occurred, or in which, although suppuration has not occurred, the soft parts have been cut too short or have been insufficiently undercut. This result is frequent even in the hands of the best surgeons, those who in the presence of an injury necessitating amputation have always been accustomed to amputate if possible through the actual seat of injury, the stump being well drained and retrimmed at a later date. But in such amputations surgeons have always in the past sought to preserve as much as possible of the soft parts which they know full well will be so very useful later when the time comes to retrim; but I raise my voice once more against the system of guillotine amputations—the soft parts being cut in the same plane as the bone—that seems to be so popular at present. The more one has been sparing of the soft parts below the level

of the bone section, the less of the bone will have to be resected later in order to adapt its length to theirs.

The treatment of these conical stumps consists in shortening the bone.

By one, or better by two lateral incisions the fibrous collar that surrounds the bone is cut up; thus are defined two flaps, each consisting of one-half of the circumference of the adherent soft parts. Some surgeons after having with the knife joined the ends of these incisions, advise deepening them right down to the bone so as to remove deliberately the periosteum from what is going to be the new end of the bone, this in the fear lest proliferation of this periosteum lead to an excess of new bone. I believe that they are wrong, and I am accustomed after having deepened the incision down to the bone, all round the adherent scar, to liberate the bone with the rugine to the height thought desirable.

This height should be calculated as for an ordinary amputation, so that the skin and muscle cover the bone end without tension; in these particular cases this necessitates in addition careful freeing of the skin by undercutting.

This skin is usually puckered into a funnel shape by the thick and dense sclerotic ring that has been cut by the freeing incisions and separated from the bone; it should be cut through completely up to where the knife, cutting on the flat between skin and deep fascia, reaches the normal loose subcutaneous tissue. Only then can the edge of the skin be doubled back. If one can so plan the incision that the scar which has been terminal becomes lateral and the end of the bone thus covered by a thick muscular flap, the result will be all the better.

In cutting the bone, the free end of which should be held with Farabœuf's forceps, it is often most convenient to use a Butcher's saw with the blade reversed, the teeth towards the frame, the bone to be cut thus occupying the space between blade and frame.

After this operation primary union should be attempted: one or two deep stitches put in the muscles, and the skin sutured. But I am sure in all such cases it is wise to provide adequate drainage, for although reinfection is less common than where the bone end itself has been infected, yet it is not unknown. It is obvious that the danger of infection could be avoided by reamputation through healthy tissues higher up the limb, but in most cases this means too great a sacrifice of length of bone.

If there be present necrosis and caries of the bone end it is best to await the loosening of the sequestra. Then the operation is performed in exactly the same way, the bone being divided well above the terminal mass of diseased new bone in which the sinuses end. In many cases, however, this high division of the bone above the gross limits of disease would result in too great a sacrifice of length of the stump; especially is this so in cases in which, the epiphysis above being involved, it would necessitate the sacrifice of the joint above or else so near an approach to it as to render it practically useless. The chief indication in such cases is to preserve every inch of length of the tibia, even if one thinks that walking with the knee flexed will be ultimately inevitable; if there be a freely moving elbow joint to save it; to retain as great a length of thigh as possible; and even in the humerus, to preserve the head of the bone,

which by maintaining the breadth of the shoulder will give a better hold for the artificial arm than if disarticulation through the joint had been performed.

In these cases, then, we must make up our minds to do incomplete operations, to perform amputations which are not always clear of the area of diseased bone, and which, consequently, it will sometimes be necessary to retrim. An attempt must be made to free muscles in such a way that they may fill up and adhere to the walls of excavated bone cavities. And if at the same time, by a few sutures, the healing of the skin can be so arranged as to avoid return of troublesome puckering, then the obligation to see that drainage is adequate and satisfactory is increased, because post-operative recrudescence of infection with the appearance of foul discharge, and even sloughing of the soft parts, is not uncommon.

The infection of wounds of war is much more lasting, much more obstinate than that in any wounds we have had experience of in civil surgery; and several times after very late secondary amputations I have had to re-operate because of rapidly spreading acute inflammation, and then later still to operate again to remove the sequestra thus produced or to excavate a diseased cavity. Such operations, of but little operative brilliance, followed by prolonged and tedious after-treatment, have resulted in my obtaining in the end stumps that are very much more useful than such as would have resulted in much less time from an originally higher amputation through healthy tissues.

I have now dealt at quite sufficient length with osteomyelitis of amputation stumps; there remains—

although it lies rather outside the range of bone lesions and infective complications—the subject of the retrimming of amputation stumps on account either of some defect of the soft parts or of amputation neuromata.

The general shape of the stump, the position of the scar, the thickness of the soft parts around the bone end, should be studied in their relation to the artificial limb that is to be worn. Troubles connected with these points are of course much more frequent in a stump that has suppurated, but often also they arise from defects in technique that I should like to mention, and they furnish indications for operative interference which, less absolutely important than those furnished by the still suppurating stump, are nevertheless often quite urgent.

A stump is really satisfactory only when the scar is supple and protected from pressure by the artificial limb, when the end of the bone is well covered with muscle, already atrophied and destined soon to become fibrous, and the skin freely movable over the underlying tissues and not tense. Now we often see stumps which fail to fulfil these conditions satisfactorily; they are not suppurating or ulcerated, but they are sufficiently conical to be very troublesome.

In the thigh and in the arm it frequently happens that the bone for 3–4 cm. is surrounded by skin only, the muscles having retracted up for this distance above the badly covered bone end. Often the skin itself is too scanty and tense—*e.g.* in thigh stumps shaped like the nose and mouth of a shark, conical, with the scar far up on the posterior surface.

In the arm the stump has no pressure to transmit

along its vertical axis; it has only to communicate movement to the artificial limb. Hence the inconvenience of an arm stump, which is incapable of bearing pressure, is not so great; but in the thigh things are very different if advantage is to be taken of modern improvements in artificial limb making, *e.g.* the transference of weight bearing from the tuber ischii to the stump itself, the surfaces and tip of which fit exactly into the rigid wooden bucket.

What obviously is of the utmost importance is the careful preservation of a length of stump at least sufficient to assure a firm hold on the artificial limb, and to guarantee its subsequent efficient action as a lever; but when amputation is performed in the lower third or quarter of the thigh, one need not be guided solely by consideration of the subsequent length of the stump; here a good supra-condyloid amputation is better than a disarticulation through the knee joint, over which the skin is tense and thin.

In the leg one of the most frequent defects results from a badly performed original division of the bone; the tibial crest has not been bevelled off, and constantly gives trouble under the thin skin covering it; or the fibula has been cut at the same level as the tibia or even lower. If to these be added an adherent terminal scar, the result of suppuration or of a circular amputation leaving insufficient covering for the bones, the stump will certainly be incapable of bearing weight. Inconvenience of this sort of course is less important when it occurs in the upper part of the leg—formerly known as the seat of election—if the old apparatus allowing of walking with the bent knee be used; but it is very considerable in modern limbs to which the stump transmits pressure along its vertical axis, and

which allow of more or less free movement of the knee joint during walking. It is necessary in such cases to shorten the bones, especially the fibula, and to remove the tibial crest; at the same time, whenever possible, the opportunity should be taken of providing the bones with a skin flap lined with a good thick layer of muscle. I am among those who recommend as a general principle flap amputations for the leg: in the lower half a large posterior flap is best (the elliptical method of amputation here gives a very good result); in the upper half the choice lies between a long external and a long posterior flap.

Before leaving the subject of amputation stumps, I will deal shortly with amputation neuromata—spindle-shaped swellings very sensitive to pressure that develop on the cut ends of nerve-trunks. They almost always result from the omission of a detail in the operative technique of amputations: the surgeon has forgotten to look for the individual nerve-trunks of the segment of the amputated limb. When found, each should be drawn down for 3 or 4 centimetres of its length, and cut across in such a way that its proximal end retracts up out of sight among the muscles there definitely out of all danger of involvement in the scar.

Amputation stumps of the arm are the commonest sites for these neuromata, which occur most often on the median and ulnar nerves. They are found very rarely after amputation of the forearm, leg, or thigh. Such neuromata prevent the use of an artificial limb, and hence their removal becomes necessary—a secondary resection of the nerve-trunk, very easily and satisfactorily carried out through a short longitudinal incision.

These cases of neuromata in the arm may be compared with a nerve lesion that develops sometimes after amputations about the foot (sub-astragaloid disarticulation, Syme's amputation, Pirogoff's amputation, etc.), in which a long plantar flap traversed by the posterior tibial nerve is used to cover the bone end. If one omits to dissect out this nerve from the whole length of the flap, cutting it across at the level of the base of the flap, its presence will often prevent the essential direct transmission of weight through the stump. It is much more difficult to rectify this than it is to set right a simple neuroma; the nerve indeed may be excised by an incision through the plantar flap, but this will result in a painful, or at least a troublesome scar; the best method is again to turn back the whole flap and resect the nerve from its deep surface.

3. Sinuses resulting from Wounds of Bone and Compound Fractures

Fractures with an open wound, much more common to-day than ever before, do sometimes heal without suppuration, just like simple fractures. All civil surgeons engaged in hospital practice know this, and they no longer trouble themselves to reckon up the number of their successes in such cases, especially in the V-shaped fractures of the tibia. But all surgeons know that when suppuration does occur things are very different, and that treatment is then to be divided into three stages: first, the arrest of infection; second, securing union in as good a position as possible; and third, the treatment of the phenomena of chronic osteomyelitis, often so tedious and obstinate.

Again, we have not been surprised that many gunshot fractures, almost exclusively indeed those caused by bullets, have healed without suppuration, just as do many cases of bullet wounds of the soft parts only. But we have been astonished that compound fractures, which are united but still have open sinuses, are apparently often regarded as almost cured, as " slight cases " suitable for transference to non-surgical institutions where any medical man can insert a drain and give at need a scrape with a curette.

And treated so, many sinuses will go on for ever : I have seen some last for months and for years before they are submitted to a suitable operation, after which they almost all heal up in two or three months. These patients, I hold, are serious cases that require the services of a well-informed surgeon, an operation which is tedious, laborious, and often difficult, and afterwards careful dressing and assiduous attention. They should be kept constantly under the care of the surgeon who performs this operation ; transference of these cases to the care of other men is strongly to be deprecated. With the concurrence of the directors of the medical services in Paris I have succeeded in keeping in touch both with patients whose fractures I have treated from the first, and also with those who, after a longer or shorter period with open sinuses, have eventually come under my care, in each case right up to the completion of their ultimate and final cure. From the two hospitals for " the severely wounded " under my charge I have been able to evacuate such cases after operation to suburban hospitals. In these no operations are performed, but here I see the cases two or three times a month, and re-admit thence any in need of further operative treatment.

For it must be understood before undertaking the treatment of these cases that secondary operations are often necessary, that after more or less sou id and apparently final healing relapses, which may be chronic, sub-acute, or even acute, are common. This is in accordance with the well-known clinical and operative history of chronic osteomyelitis. In order to progress from the simple to the more complicated I will first say some words about wounds of bones, and will then devote myself to fractures.

A. Wounds of Bones

(*a*) *Wounds of the shafts of bones* are not common, for a projectile which strikes the compact bony cylinder of the shaft almost always fractures it completely. However, the following types are occasionally seen :—

1. A bullet or shell splinter without opening up the medullary canal cuts a groove of varying depth either more or less in the direction of or else at right angles to the long axis of one of the surfaces of the shaft.

2. A rifle bullet—and especially a round lead shrapnel bullet—when spent may flatten itself out against a bone, sometimes causing a simple contusion of the surface of the shaft, more often burying itself in and splintering the bone.

A simple bony contusion with infection of the neighbouring soft parts is almost identical with the condition that occurs so often in cavalry regiments from the kick of a horse against the inner surface or crest of the tibia.

The affected piece of bone, bared of its periosteum,

lies at the bottom of a suppurating wound and undergoes necrosis over a varying extent and depth, and finally forms a thin scale-like sequestrum with one surface—that originally superficial—smooth, the other irregularly eaten away, and with its edges everywhere serrated by the process of rarefying osteitis.

Except in cases complicated by severe inflammation of the soft parts, diffuse osteomyelitis and extensive necrosis result but rarely ; one might therefore be led to expect an early spontaneous elimination of so superficial a sequestrum at the end of the five or six weeks necessary for its liberation.

Often indeed things do happen thus, especially in the skull, allowance being made for the relative frequence in simple contusion of associated fissures of the vault or of comminution of the inner table. One can here observe the imperceptible exfoliation of the bone, the surface of which at first white, smooth, and bare, becomes little by little flecked with red spots, and later uniformly covered with granulations. In other cases the sequestrum loosens and comes away almost without the aid of forceps. Sometimes, however, the sequestrum is larger than the cutaneous opening of the corresponding sinus, which has then to be enlarged with the knife before the curette can be used. Rarely do its borders become caught in an overgrowth of new sub-periosteal bone ; and even in these rare cases it generally manages to escape, so that, on the whole, such cases are of little practical importance. Operations should not be performed until the sequestrum is loose, for until this has occurred it is impossible to be certain of its size ; premature operations are thus likely to do too much or too little, either to remove the whole thickness of the bone when the deeper part

would otherwise have survived, or else to leave edges which necrose later and necessitate re-operation.

A contused wound of the superficial surface of the tibia is often of a discouragingly chronic nature, less because of enclosure of the sequestrum than because of delay in healing of the soft parts. There has perhaps been considerable destruction of the skin, which here is thin and stretched over a bone that possesses but little subcutaneous covering. Epithelial ingrowth over the granulating surface of the bone makes little or no progress, and when healing does take place, the scar is thin, adherent, badly nourished, and liable to frequent ulceration.

Treatment should consist in excising the ulcerated patch right down to the bone, in scraping away granulations from the surface of the bone, and in the removal of sequestra. The bony surface should be scraped until healthy bone is exposed, and then, after suitable undercutting, the skin should be sutured and the wound thus closed ; as in all cases where secondary suture of a wound that has suppurated is attempted it will be wise to insert a drain.

When sequestrum formation follows contusion of a bone lying deep under a thick muscular covering, *e.g.* in the shaft of the femur, a sinus results which frequently keeps on discharging for months until the necrosed bone is exposed and removed. The edges of such a sequestrum are frequently overlapped by new sub-periosteal bone, but usually this is of no great extent or bulk, and there exists no real sequestral cavity. The operation will thus consist merely in slitting up the sinus track so as to allow of the detachment and removal of the sequestrum—easily effected by one stroke of the curette ; despite the thickness

of the soft parts, the conditions are the same as we have described in the case of the skull.

Before operating the surgeon may, if he so please, ascertain whether the track leads to bare bone or not, but in these cases where so long a track runs through so great a thickness of muscle, it is not nearly so easy as in the skull to make certain whether the sequestrum be loose or not. This operation differs very much from the much more serious one that becomes necessary when a cavity remains in the bone after the removal of all sequestra.

When the sinus, although at first sight apparently indistinguishable from those with which we shall deal later, leads to bone that is not thickened, when on examination new bone formation is found to be absent, and when the probe does not seem to enter a bony cavity, the presumption is that the sequestrum will be found to be superficial, with but little sub-periosteal encasement. The information furnished by radiography is interesting; the X-ray plate shows a bone of normal density without any transparent central patches; its edges are clear cut, straight, and without irregularity except at one definite spot, where may be seen the dark shadow of the sequestrum that is being liberated by rarefying osteitis, its inner border at present but imperfectly distinguishable from the irregular surface of the bone itself, whilst no shadow of newly-formed bone appears on its outer side. This gives information which is interesting but not always reliable, since a bone may contain many sequestra deep in its shaft, and yet give an almost normal appearance on an X-ray plate. Still an experienced eye will usually succeed in detecting slight points of abnormality. I shall return to this point later when dealing with the radiographic

characteristics of bony cavities and of enclosed sequestra.

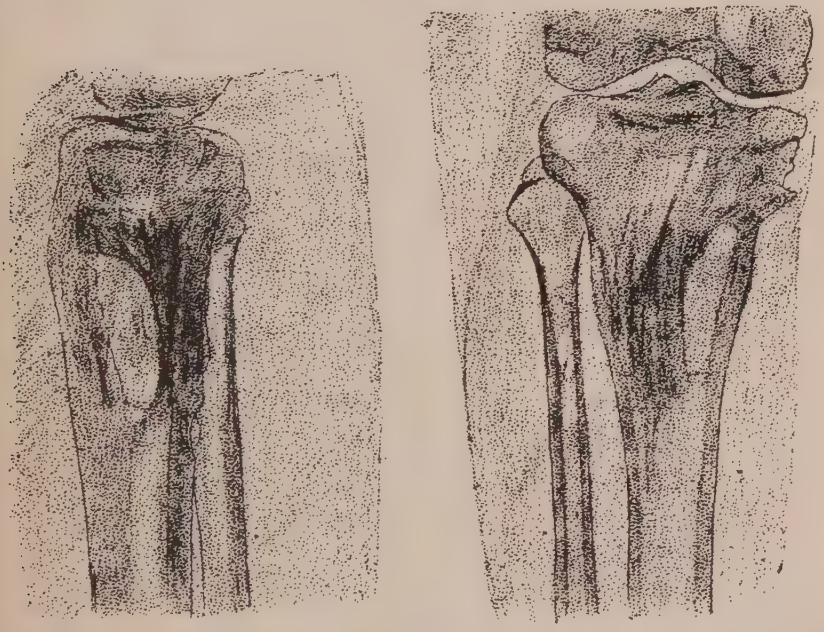
Traumatic furrows and incomplete fractures limited to one surface of the shaft of a long bone may end similarly with the formation of superficial sequestra, but often—and more especially in the cases where there is splintering of the shaft—these are complicated by fissures opening into the medullary cavity and fragments either partly adherent or completely detached. If at the same time, and on the top of such a state of affairs, infection is introduced and becomes active, the osteomyelitis that results runs a course, and has consequences which do not differ from those that occur in compound fractures without displacement of fragments.

(*b*) *Wounds without complete fracture of cancellous bone, i.e.* of large epiphyses and the small flat bones, are not infrequent, and occur either in punctured wounds of the soft parts, or with a single entrance wound, the foreign body being retained. The projectile is sometimes a rifle bullet, sometimes a small piece of shell casing, or a round shrapnel ball.

Tracks from punctured wounds often do not suppurate; healing takes place in a few days, frequently after an effusion of blood has taken place into the neighbouring joint, especially often into the knee joint.

Suppuration, however, is usual if a foreign body, projectile or piece of clothing, remains in the track of the wound. The aseptic healing of a bullet or even of a piece of shell in an epiphysis does, however, sometimes happen; sometimes, too, there occurs but a slight limited infection, which soon disappears after the removal of the foreign body, even though this has remained in the bone for some time. Let no one, how-

ever, suppose that the occurrence of these favourable events is anything but unusual; rarefying osteitis is the rule (figs. 44 to 47), a process that usually spreads rapidly to all parts of the mass of spongy bone. A large cavity is then inevitable in a position which is



FIGS. 44 and 45.—Patient twenty-eight years of age; wounded, 3rd March 1915; perforation by a bullet of the upper tibial epiphysis. Radical operation, 25th August 1915. X-ray taken, 28th March 1916. Healed by 6th April 1916, with free movement of the knee joint

most unfavourable, both because of the inevitably prolonged period of healing, and also because of the frequency with which a chronic synovitis follows. Whilst, then, in the case of a bullet track with but tiny skin punctures it is expedient to wait before operating until suppuration has definitely occurred, and not to commence seeking for hypothetical pieces of clothing—

nor even to submit such cases to any sort of continuous antiseptic irrigation—on the other hand, operation should be early, even immediate, in cases where radiography shows the retention of a foreign body, and this is almost always the case in wounds with but one entrance. One will abstain from operation only

FIGS. 46 and 47.—Patient forty-one years of age; wounded, 25th September 1916, a piece of shell passing right through the soft parts and the upper tibial epiphysis. Caries without sequestra is shown spreading down a little into the shaft. X-rayed, 24th March 1916 Operation, 11th April. Still unhealed in September.

where—what does happen sometimes with bullets, and exceptionally with pieces of shell and broken bullets—the encysting of such a foreign body is already far advanced and the patient is free from all pain and all signs of subacute or chronic arthritis.

Nevertheless, even in these cases, if it can be done without much risk, I usually extract the bullet, for I

have learned by experience that although these foreign bodies may at first seem to be aseptic, later recrudescence of inflammation about them occurs very much more often than we believed in the early days of the war ; it is wise never to allow rarefying osteitis either time or opportunity to develop in an epiphysis, for even in cases where the infection is of the slightest, it is rare for the process to be localised by the occurrence of osteosclerosis around it.

B. Compound Fractures with Chronic Sinuses

Pathology.—The chief characteristic of gunshot fractures is their comminution.

This includes two phenomena :—

(i) The complete shattering of the bone at the point of reception of the njury.

(ii) The accompanying fissures or cracks that radiate a variable distance up and down the shaft of the bone from the actual primary seat of injury.

One result of this is the extensive opening up of the medullary cavity, another is the production of a number of bony fragments at the point of injury ; of these latter some are from the beginning loose, unattached either to the main mass of bone or to the stripped-up periosteum ; others remain adherent, *i.e.* they are separated from the bone shaft, but still retain connection with periosteum, and through it with the neighbouring soft parts.

When the fracture is not compound, not infected, such an extensive shattering does not interfere at all with the final attainment of sound union. Not only do the adherent fragments survive and take an active

part in the union, but even the loose pieces join up with these and assist in the callus formation. It even happens more frequently than one might imagine, in fractures where the bullet has broken up into innumerable pieces, that these become set in the callus along with the fragments of bone. In such cases this callus of course remains for a long time excessive in amount and inflamed and painful; however, it does not suppurate, but gradually becomes remodelled and lessens in size, complete union and healing taking place without the necessity for any operative intervention, just as in a simple fracture. I shall return later to the radiographic appearances of these metallic fragments, which become so embedded in bone as to be really no longer foreign bodies whose extraction is either feasible or desirable.

However, if the seat of fracture is infected two processes must be distinguished :—

(i) The separation of necrosed bone.
(ii) The consolidation of the fractured bone.

1. *The separation of necrosed bone.*

It is inevitable that fragments which are from the first completely detached from all their connections should die and at once form sequestra. The same fate soon overtakes most of the partially adherent fragments, whose periosteal connection is not long in giving way. These two varieties of sequestra are of the same general shape—that is to say, their surfaces are smooth and clean, their edges and points sharp, without any of those fine serrations that are at once the outcome and the sign of a process of liberation by rarefying osteitis. Clinically they are almost identical, no great time having elapsed between the

immediate isolation of the former at the time of the fracture and the final and total denudation of the latter in the suppurating area.

As regards the two ends of the shaft, however, the pathological changes are different. They are the same as those we have described as taking place in the end of the bone in an infected amputation stump. The ends of the fragments, denuded as they are of their periosteal covering, undergo necrosis over a variable length. This necrosed bone in time becomes loose and then forms secondary sequestra, which show signs of their mode of production by the presence on their separated surfaces of those fine serrations characteristic of fragments set free by rarefying osteitis. Other secondary sequestra—usually quite small—are of a purely inflammatory origin. Like the sequestra of spontaneous osteomyelitis, these bear serrations on all their surfaces and edges. The clinical difference, then, between primary and secondary sequestra is due to the gradual isolation of the latter by rarefying osteitis : these pathological observations have a practical significance for the surgeon that will appear later.

I shall not repeat what I have already written in dealing with osteomyelitis in amputation stumps, about the occurrence, to a greater or less extent, of infection of the medullary cavity, and about the involvement of neighbouring epiphyses in the septic process. The simultaneous involvement of both epiphyses takes place only in such cases of complete shattering of the shaft as is practically incompatible with the preservation of the limb. Usually a fracture near the middle of a shaft is not complicated by extension of the infection to the epiphysis. This

does, however, sometimes occur, especially when the bone has been fractured near the junction of the shaft with the epiphysis, where the medullary canal has come to an end and the compact bone of the shaft is gradually being replaced by a trabecular structure of cancellous bone.

2. *The consolidation of the fractured bone.*

Union of the fragments of the bone takes place side by side with the liberation of the secondary sequestra. It is effected partly by intermediate callus, partly by callus uniting those parts of the shaft that lie beyond the area of necrosis, and partly by sub-periosteal new bone formation. This last plays the chief part in the union in cases where necrosis of the fragments of the diaphysis has been extensive, and also especially in cases where union is taking place despite marked angulation. In this way we get produced a sheath of new bone, and a sequestral cavity in which the various sequestra lie enclosed. This cavity communicates with the tissues lying outside the bone by perforations of variable size and number in the encasing sheath of new bone. Often there is but one such perforation of spontaneous origin, that has been in existence from the earliest days of the fracture. After operations have been performed for the removal of sequestra or foreign bodies, however, they are frequently more numerous and of larger size.

Whether the fragments are in good or bad position, with or without angulation, the mode of formation of the cavity, by the laying down of sub-periosteal callus, remains as a general rule the same. But the amount of the callus, the dimensions and shape of the cavity, vary greatly with the accuracy of reduction of the fracture.

The simplest case is that in which the fragments lie end to end without any displacement; in such it is rare for the infection to be extensive; the two fractured ends unite; a considerable length of the medullary canal of each becomes obliterated by a process of condensing osteitis similar to that we have seen taking place in amputation stumps; around the ends of the two fragments the sheath of sub-periosteal new bone becomes compact and dense; the sequestra are usually small, and granulation tissue but slightly in evidence.

When the loss of bone has been extensive but the periosteal sheath well preserved, and when union with gross displacement or malposition has been avoided by adequate immobilisation, then the bone will unite, with shortening certainly, but with little or no angulation; apart from this shortening, however, a condition of affairs very similar to that we have described obtains, except that the cavity will be larger and more irregular, the sequestra bigger, and the production of sub-periosteal callus excessive. The two ends of the bone coming into some sort of contact unite over at least a part of their surface, and intermediate callus still plays a not unimportant part in the attainment of union. In such cases, when early operation, undertaken on account of serious infective complications, has cleaned out the infected seat of fracture, shortening is inevitable; nevertheless by the use of suitable apparatus and careful attention, especially by continuous extension in fractures of the femur and humerus, a good result may be obtained, union resulting without angulation the sequestral cavity that remains being usually of a type in which rapid final cure is not difficult to secure

The conditions are very much less favourable, however, when overlapping and angulation occur; such still too frequently result in fractures of femur, partly because it has not been possible to obtain reduction of the fracture, partly on account of some inadequacy or defect in the immobilisation. It is not always possible, for instance, properly to reduce or immobilise a sub-trochanteric fracture complicated by considerable comminution and by the presence of severe inflammation that necessitates multiple long incisions. In such a case the fragments remain only in very poor contact; intermediate callus becomes an agent of only secondary importance in the union, the chief part being played by a deposit of new bone in successive layers from the periosteum that has been stripped from the shaft for a variable but always considerable distance up and down. In such a case the sequestral cavity that results is of most irregular shape, with walls of new bone of great, sometimes enormous, thickness. This new bone is for the most part dense, attaining in the course of time to an extreme degree of hardness. In some places, however, this is not so—it is rarefied, excavated by pus or granulation tissue; in other places it is hollowed out into small abscess cavities and tunnels that become lined with granulations.

In these cases also there may take place a great extension of the osteomyelitis, with the formation of very long sequestra, which may even extend to almost the entire length of the diaphysis, sequestra which are identical in their appearance and in their origin with those occurring in spontaneous osteomyelitis.

It is this type of case, too, in which the chronic

infective process, if left to itself, tends to spread, so that unless it be cut short by a radical operation, more and more bone becomes converted into granulation tissue, and the cavity undergoes a progressive increase in size.

This persistence of the inflammatory process should not be forgotten; slow doubtless it is, but characterised by no natural tendency to cease, involving the late development of sequestra in places originally altogether outside the seat of injury and infection. It thus produces a gradual increase in the extent and severity of the bone lesion. Attacks of subacute, if not of acute, osteomyelitis often supervene, hence this traumatic process follows the classical course of the spontaneous osteomyelitis of childhood. Just as in this latter disease, so in this traumatic form, the extension of the pathological process into an epiphysis may result in serous, plastic, or suppurative arthritis of the neighbouring joint. Even in the absence of such an arthritis, however, the range of movement of the joint may be seriously limited by the overgrowth of the articular end of the bone.

Sequestra large or small are an almost invariable occurrence; in no case that has been under my care from first to last have they been entirely absent, and in hardly any that have come to me later with open sinuses, and in these rare cases there has always been present a cavity from which they had either spontaneously emerged or been surgically removed. The persistent sinus in such cases is due to the persistence of osteitis, to the existence of a suppurating cavity, the obliteration of which should be at least as much the object of operation as the removal of sequestra.

As regards flat bones, I have already said that the enclosure of sequestra is but rarely of importance in the skull. Such is not the case, however, with the innominate bones and scapulæ, in which the sequestra do become enclosed in cavities formed by sub-periosteal deposit of bone. This occurs constantly in traumatic lesions of the iliac crest and of the angle and the axillary border of the scapula. In the scapula, too, it is quite common to find a cavity or tunnel containing sequestra in the cancellous mass at the attachment of the spine to the body of the bone. As regards short spongy bones, especially the larger bones of the tarsus, I have nothing to add to the description I have already given of the formation in them of cavities, often containing sequestra, by a process of widespread caries. But I wish to insist on the occurrence—almost inevitable in these cases—of infection of the neighbouring joints, on the obligation to anticipate more or less ankylosis of such joints, and hence to take steps to prevent the development of such positions as will, on the occurrence of ankylosis, lead to poor functional results. I shall deal with this subject later.

This applies also to all infected fractures of epiphyses in which the corresponding joint suppurates and later undergoes complete bony ankylosis, and in which the maintenance of the "ideal" position of election of the limb is a matter of the greatest importance. The persistence of a chronic sinus in these cases is due, however, not to the joint lesion but to caries of the epiphysis.

THE RADIOGRAPHIC STUDY OF TRAUMATIC OSTEOMYELITIS

We shall not enter into a theoretical discussion of the interpretation of the radiographic appearances of various bone lesions; two brief statements of fact will serve as a *résumé* of the subject :—

1. Caries or rarefying osteitis produces areas of abnormal permeability to the X-rays; these appear in a negative[1] as irregularly shaped dark patches, separated by the lighter bars and areas that correspond to the intervening portions of denser bone.

2. Sequestra, on the other hand, are abnormally opaque and impermeable to X-rays; hence these show up in a negative as very light spots, often recognisable by their pointed ends and clean-cut, often serrated, borders. They are less opaque by far, however, than metallic fragments; but it is important to remember that a piece of metal, especially a piece of lead, that has struck and fractured a bone can so coat a fragment of bone—sequestrum or not—with a thin metallic layer as to make it as impermeable to the rays as the foreign body itself.

If the skiagram of a bone, the seat of an old-standing spontaneous osteomyelitis dating back to childhood, be first examined (figs. 48 and 49), these inequalities of transparency will appear very evident; it will be noticed besides that the bone is generally enlarged and irregular in outline—this because outside the original shaft that throws a dark shadow of quite normal shape there appears a distinctly lighter

[1] If one is examining a print and not a negative, of course the reverse holds good—parts impermeable to the X-rays appear dark, parts abnormally permeable, light.

shadow of irregular outline due to the presence of an involucrum of sub-periosteal origin (fig. 48).

A first type is represented by rarefying osteitis,

FIGS. 48 and 49.—X-ray appearances in a case of hyperostosis, with intermittently discharging sinus in an adult who suffered from a chronic osteomyelitis dating from childhood. No sequestra. The unequal patches of rarefaction and the distinction between the original shaft and the new sub-periosteal bone are clearly seen. Note the club-shaped enlargement of the condylar and supra-condylar region, common in these cases, and the principal cause of stiffness of the knee in the extended position. Compare this with the traumatic osteitis without sequestra (and without hyperostosis) in figs. 50 and 51, and the different appearances when there are little sequestra in the cavity (figs. 52 and 53).

without sequestra—these may have been removed or may never have been present—following the penetration without complete fracture of an epiphysis

FIGS. 50 and 51. Patient aged twenty-nine. Wounded with shrapnel, 18th September 1914. X-ray, 18th March 1916, after a radical operation performed on 26th January 1916. Healed by the end of April.

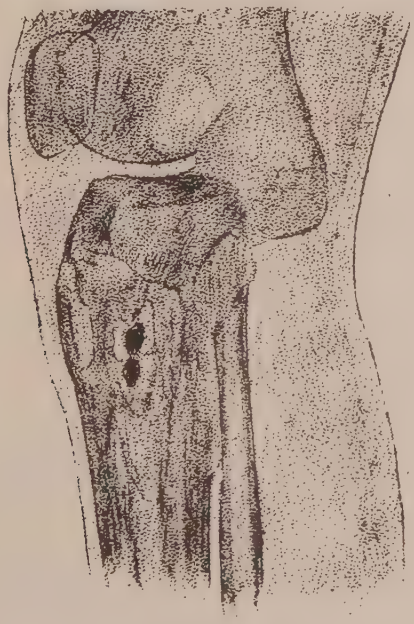


FIG. 52.—Patient aged twenty-seven. Wounded on 17th December 1914. X-ray, 27th January 1916. Radical operation 1st February. Sinuses still present in September.

(figs. 50 and 51; see also pp. 609 610, or from the penetration of a diaphysis, no sign remaining of any fracture, although there may originally have been longitudinal fissuring or a transverse fracture without displacement (figs. 53 and 54). Attention should

FIG. 53.—Wounded, 18th November 1914. X-ray, 25th February 1916. Radical operation, 28th February. The cavity extended very far downwards. Healed by 30th May.

be directed in these radiograms to the great extent of the cavities existing in the epiphyses or encroaching on the shaft. There appears in them no appreciable amount of new sub-periosteal bone. Figs. 55–60, on the other hand, show both displacement of fragments and more or less deposit of sub-periosteal bone. Figs. 55–60 and also 53 and 54 show the presence of cavities

containing numerous sequestra—the latter recognisable by the dark shadows they throw, much less dark, however, than those of metallic fragments. Fig. 56

FIG. 54.—Patient twenty-four years old. Wounded, 22nd August 1914, by a shrapnel bullet; refused to allow his leg to be amputated in Germany on the eighth day. X-rayed, 26th February 1916. A cavity of great extent is present in the shaft extending down further than the X-ray would lead one to expect. A first operation was performed 2nd March 1916 and three sequestra removed. The lower end of the wound remained open as a sinus, and on re-operating on 30th May, and again on 12th July, small narrow cavities lined with granulations were discovered still further down the shaft, on the latter occasion extending to within two finger-breadths above the malleoli. Healing was complete by 25th August 1916, the scar remaining adherent to the groove in the bone and covered with very thin skin.

shows two small fragments embedded in the lower end of the tibia. In fig. 54 one sees a cavity in the shaft containing sequestra, the fracture having

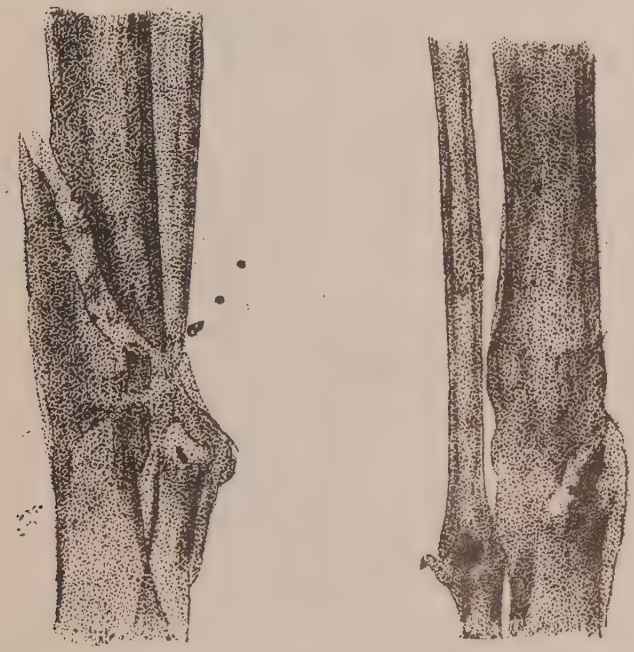
united without displacement. In figs. 56–58 displacement of fragments is shown and the sub-periosteal new bone taking part in the formation of the sequestral cavity. Figs. 55–58 are also examples of fracture of

Figs. 55 and 56.—Patient thirty-three years old; wounded by a piece of shell on the 1st March 1915; attempt at suture on 16th March; profuse suppuration; several operations for the removal of sequestra. 7 centimetres of shortening; a sinus still persisting. X-rayed on the 25th March 1916. On the 12th of April a radical operation was performed; a condition of osteitis was found, but no sequestra; the diseased bone was removed. This patient was still under treatment and unhealed in September.

the two bones of the leg ending in a synostosis; whilst in fig. 54 it will be noticed that the soundness of the fibula has been effective in preventing displacement of the fragments of the tibia.

CLINICAL STUDY.

An increase in the size of the bone and the presence of a discharging sinus constitute the two chief clinical signs of traumatic osteomyelitis.



FIGS. 57 and 58.—Patient, twenty-one years old, was wounded on the 27th of September 1915. The diseased bone was scraped on the 18th March 1916. X-rayed on the 23rd of March; cavities of both the tibia and the fibula are shown, containing sequestra. Radical operation performed on the 5th of April 1916; healing complete by the 13th of June.

This increase in the size of the bone varies greatly in different cases; in most it is considerable, in a few enormous, especially where mal-union has occurred with overlapping or marked lateral displacement of fragments.

When it involves the middle of the shaft the bone becomes spindle-shaped ; when one end of the shaft, this end becomes club-shaped—the shaft greatly thickened towards the epiphysis, but in the opposite

FIG. 59.—Patient, thirty years of age, was wounded in Serbia on the 25th of November 1914. X-rayed on the 26th of February 1916. A cavity in the bone lined with granulations but without sequestra. Operation on the 2nd of March ; healed by the 30th of May. The sinus opened again with slight suppuration on the 31st of July, and did not heal until the 19th of August. Walking is rendered difficult by the existence of a laxity of the ligaments of the knee joint resulting in a genu recurvatum that is quite apparent during standing.

direction, gradually decreasing in diameter until normal thickness is reached at variable distance toward the far epiphysis.

Hyperostosis of the whole shaft, with a thicker

FIG. 60.—Patient thirty-one years old, wounded by a piece of shell on the 1st of March 1915. Removal of fragments on the 23rd of April 1915. Sequestra are lying in the midst of the interfragmentary callus. X-rayed on the 24th of March 1916. Operation on the 2nd of April; scraping of the upper fragment, which was projecting beyond the lower downwards and outwards; rarefying osteitis of the lower fragment. Finally healed in July.

Fig. 60 represents a type of fracture with great displacement and overlapping in which the callus is almost exclusively periosteal, in which there is no real contact of the actual fractured surfaces, and in which the sequestrum is enclosed in the periosteal callus lying between the bone-ends. It should be noted that the process of rarefying osteitis of the lower fragment did not extend nearly as far as the epiphysis, and that healing took place relatively quickly; on the other hand, this may be contrasted with the uncertainty and slowness of healing in cases where the cancellous tissue is affected (figs. 46, 59, 61, for example).

mass at either end, is seen only in cases where there has originally been a complete shattering of the whole diaphysis; this is rare, as such cases usually end sooner or later in amputation.

EXAMPLES OF SEQUESTRA ENCASED IN SEQUESTRAL CAVITIES OF THE SHAFTS OF LONG BONES.

FIG. 61.—Patient aged thirty years; wounded by a bullet on the 20th of September 1914. A cavity remains containing one sequestrum despite three operations (in Germany). Rarefying osteitis of the epiphysis. X-rayed on the 25th of February 1916. Radical operation on the 3rd of March. Still discharging in September.

On inspection the increase in size and the abnormal shape of the bone are seen, but their full extent may not be appreciated, unless it is remembered that when the limb, which is so abnormally cylindrical, and whose

natural prominences are lost, is further examined, it will be found that the muscles are much atrophied.

On palpation, however, the irregular mass of bone will be felt immediately under the skin, presenting in many cases marked projections that may be recognised as the original ends of the displaced fragments,

FIGS. 62 and 63.—Patient aged thirty-three years; wounded by a bullet on the 11th of October 1914. Several times scraped. A cavity remains containing six large sequestra. Operation on the 7th of April; healed by the end of April; on the 5th of May, however, another sequestrum appeared, the sinus being healed again by the 26th of June.

rendered, however, smooth and regular in outline by subsequent deposit of sub-periosteal callus. The whole mass is of bony hardness; the skin over it, hotter than on the opposite side, is thickened, infiltrated, and unyielding, and the seat often of a solid chronic œdema of inflammatory origin. In some cases pain is present intermittently, in others almost completely or entirely

absent; in some cases on palpation the bone is quite insensitive, in others special localised areas remain extremely tender.

FIG. 64.—Patient aged thirty-three years; wounded by shrapnel on the 18th of January 1915. X-rayed on the 23rd of March 1916. Operation on the 8th of April with correction of stiff contracted toes. Recommended for discharge from the Army; still with a superficial sinus on the 21st of July.

Note in this case: first, the pieces of lead scattered through the lower fragment of the tibia; second, the sequestrum in front of the tibia; third, the obliquity of the lower fragment downwards and forwards, a displacement that necessitates flexion of the knee if the sole of the foot is to be put flat to the ground (see Chapter V.).

This abnormal mass of bone communicates with the exterior by means of one or more sinuses that open either through the original wounds of entrance or exit, or through one or more of the tracks due to early abscess formation, or through which a later

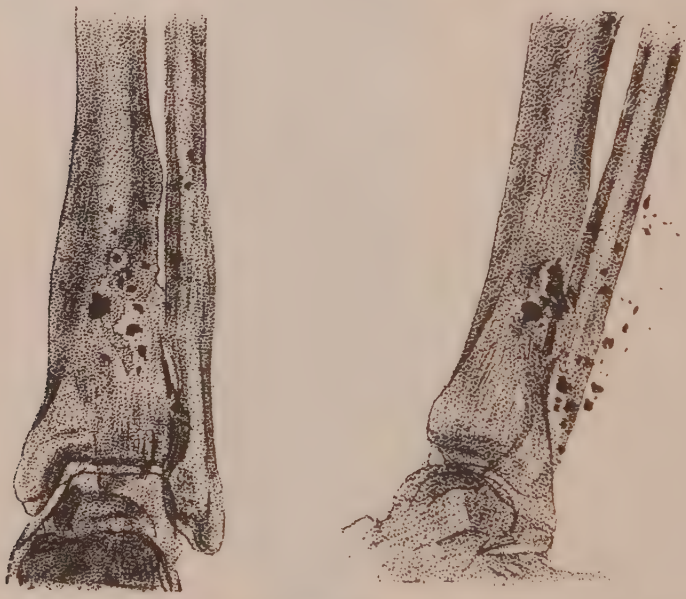
and more chronic abscess has been opened. It should be understood that I am not speaking of sinuses that

FIG. 65.—Patient of thirty-six years; wounded by a rifle bullet on the 26th of November 1914. X-rayed on the 29th of January 1916. Operation with removal of a sequestrum on the 15th of February 1916; healed by the 22nd of March.

Note the rapidity of the healing which results from the removal of the sequestrum encased in a cavity with compact walls. Note also the dislocation of the hip joint with disappearance of the femoral head.

result from operation undertaken for the cure of an old-standing focus of osteomyelitis; in some cases these do remain open for a long time.

These sinuses almost always run a straight course to the bone. They commence at some point on a scar, which, usually soft and supple at its ends, remains thickened, hard, of a brownish colour, and inverted



RADIOGRAMS SHOWING THE PRESENCE OF SEQUESTRA AND METALLIC FOREIGN BODIES (a shattered bullet, Figs. 66 and 67; small pieces of shell casing, Fig. 68).

FIGS. 66 and 67.—Patient aged twenty-six years; wounded by a rifle bullet on the 28th of January 1915. X-rayed on the 6th of April 1916. A cavity remains in the back of the tibia, containing two sequestra, non-invaginated. Fragments of metal from the shattering of the bullet. Operation on the 10th of April. Discharged, almost healed, on the 20th of May to a hospital for slightly wounded native soldiers.

to form a funnel-shaped depression around the opening of the sinus. This runs towards the bone, to which it adheres, through a thick mass of dense scar tissue, in which lie the remains of the muscles and tendons of the part. Rarely the cutaneous opening leads

almost directly to the bone without running a course through the soft parts ; this occurs where the affected portion of the bone is subcutaneous or nearly so, around epiphyses, over the internal surface of the tibia, the posterior edge of the ulna, etc.

FIG. 68.—Patient aged thirty-six years ; wounded on the 7th of August 1915 by a piece of shell. A cavity persisted despite the removal of sequestra on the 18th of January 1916. X-rayed on the 9th of March 1916. Operation, obliteration of the cavity, and removal of the foreign bodies, on the 24th of March. Healing complete by the 11th of April. Stiff elbow with only 15 to 20 degrees of flexion and extension.

S, sequestra ; M, metallic foreign bodies.

The discharge from these sinuses is sometimes serous, sometimes thick pus ; in some cases abundant, in others scanty. Sometimes all that appears is a dry crust adherent to the scar. At first this may be con-

sidered the covering of a superficial ulcer—actually a not uncommon condition to find in the last stages of these cases, but on removing it, the point of the probe soon finds its way into the track of the sinus.

LESIONS OF THE UPPER END OF THE HUMERUS WITHOUT INVOLVING THE SHOULDER-JOINT.

FIG. 69.—Patient aged thirty-three years; wounded on the 5th of March 1915. X-rayed on the 1st of April 1916. Operation on the 12th of April (five sequestra); healed on the 21st of May.

On the 1st of September a small sinus reopened after the patient had returned home. The joint is quite free on passive movement, but active movement of it is absent owing to atrophy of the deltoid (probable division of the circumflex nerve).

Even when there is but little discharge the surrounding skin is often inflamed, eczematous, covered with scabs, or else discharging serum or pus over quite a considerable area, sometimes indeed around

the whole circumference of the affected segment of the limb. Such a condition of the skin is often very chronic, persisting after the complete healing of the sinus itself, and sometimes, because of the discharge, leading to the belief that the sinus is still open; such

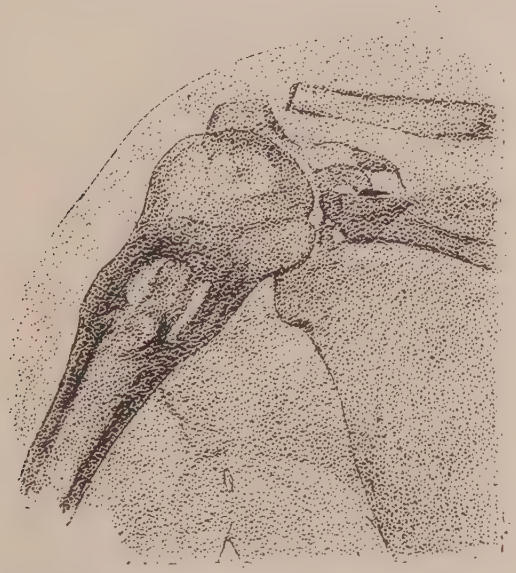


FIG. 70.—Patient aged twenty-two years; wounded by a rifle bullet on the 20th March 1915. A granulating cavity persisted after the removal of sequestra for five months from the 15th of September 1915. The cavity, in which a thread of silk was found (? origin) was scraped out on the 28th of February 1916. I thought that this would have been all that was necessary, but, a sinus persisting, I was forced on the 9th of September to remove the anterior wall of the cavity.

has been the actual state of affairs in several cases sent to me with the diagnosis of persistent old-standing sinuses. Usually the track of the sinus is so straight that the probe finds its way without difficulty to the bone; almost always indeed bare bone can be felt. According to the condition present, the probe

gives the sensation of contact with a surface of bare bone, of scraping along the rough wall of a tunnel, of engaging in a mass of soft carious bone in passing through the trabeculæ of which the probe gives a special sensation of very fine crepitus, or, lastly, of contact with a loosely lying sequestrum.

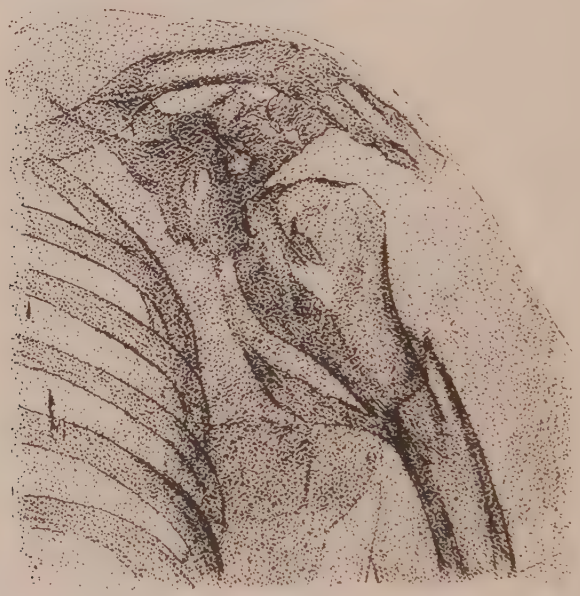


Fig. 71.—Patient aged thirty-six years; wounded by a bullet on the 13th of January 1915; fracture of the humerus; a cavity formed at the base of the glenoid cavity. X-rayed on the 26th of March 1916. Operation on the 1st of April; healed by the 1st of August, after the persistence for about a month of a sinus posteriorly.

When struck with the probe necrosed bone gives a clear, sharp note. To determine with the probe, however, whether or not such necrosed bone is loose, forming a sequestrum, is not always an easy matter; an acute ear will detect in the sound produced by a sequestrum a special, almost metallic, note, whilst

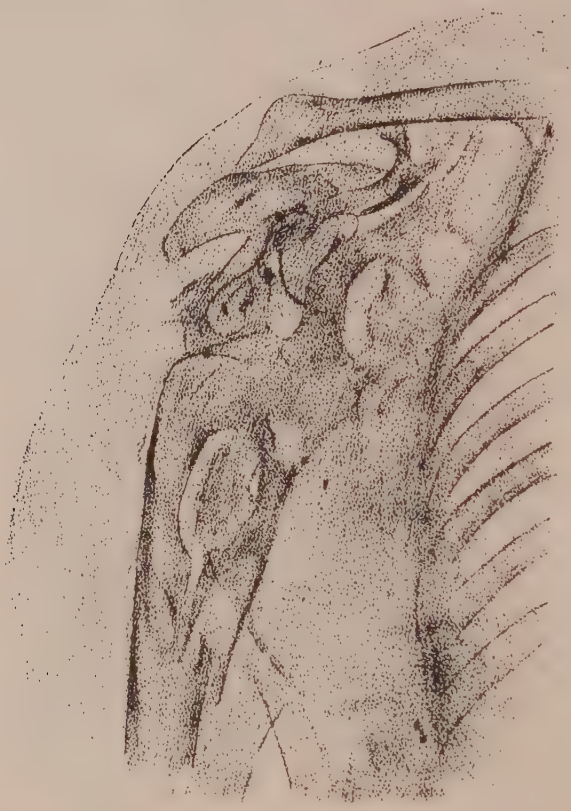
the skilled hand will perceive that the bone gives a little with the probe, and thus possesses a small to-and-fro movement. But we can be quite certain of this mobility only in those rarer cases in which,

FIG. 72.—Patient aged thirty-three years; wounded by a bullet on the 25th of March 1915; had already submitted to three operations. X-rayed on the 15th of April 1916. Radiogram shows a large cavity due to rarefying osteitis without any sequestra. Radical operation on the 29th of April.

by introducing probes through two different sinuses into contact with the same piece of necrosed bone, movement can be transmitted from one to the other through the sequestrum.

When several sinuses are present, no matter what the position of their external openings and their

lengths, they generally all converge towards the same



LESIONS OF THE HUMERUS AND OF THE SCAPULA, WITH BONY ANKYLOSIS OF THE SHOULDER JOINT.

FIG. 73.—Patient aged forty years; wounded by a bullet on the 12th of January 1915; six operations; ankylosis with the presence of sinuses; X-rayed on the 18th of April 1916. This man, who had eventually to be evacuated for misbehaviour, was a typical example of a case in which stiffness of the elbow and the fingers had resulted from the injudicious use of an arm-sling; free use of these joints was, however, spontaneously recovered in a few days, although the patient was not at all anxious to co-operate.

part of the bone, towards a single cavity with several cloacæ, and often, especially if the sequestra have

already been removed, the points of probes passed along two or more of the sinuses may be felt to meet.

It is not often possible with the probe to determine accurately the shape, directions, and size of the sequestral cavity; this is possible only in those cases in which the sinuses lead down directly into a cavity in a subcutaneous bone.

FIG. 74.—Patient aged twenty-four years; wounded on the 6th of December 1914. Removal of sequestra 25th of February 1915; X-rayed, 29th of March 1916. Rarefying osteitis without sequestra; operation, 27th March. He had to be evacuated for misbehaviour, 13th May, whilst still under treatment, although healing appeared to be progressing well.

In many, perhaps in most, cases small sequestra issue spontaneously from time to time from these sinuses carried out by the flow of pus, which during the few days preceding has usually been increased in amount and accompanied by more inflammation of the surrounding parts. I lay stress on this point, that the natural elimination of sequestra is a normal and usual occurrence in the course of chronic osteomyelitis,

whether traumatic or spontaneous : it is a phenomenon that has been familiar to surgeons for centuries, but it is just as well to remember this in present times, when certain claims based on its occurrence are being

CAVITIES WITHOUT SEQUESTRA discharging by a sinus, at first sight insignificant; the "cloaca" had been previously enlarged by totally inadequate scrapings. The probe passed into an extensive cavity.

FIG. 75.—Patient aged thirty-three years; wounded by a shrapnel ball, 25th September 1914. X-rayed, 18th February 1916; a sinus persists after an inadequate operation of conversion of the cavity into a gutter (four operations—scrapings—from October 1914 to April 1916). Obliteration of the cavity, 21st February and then again 5th September.

made on behalf of various therapeutic agents ; with these I will deal later. It will be as well also to state explicitly, and once for all, that this spontaneous

appearance of sequestra hardly ever leads to permanent and ultimate cure. It may lead to an apparent local improvement, to a diminution of the suppuration; where in some cases the sinus does become smaller

FIG. 76.—Patient aged thirty years; wounded by a bullet, 25th September 1914; removal of sequestra, 12th December 1914. X-rayed, 20th January 1916. Cavity in the shaft without sequestra; operation, 24th January; healed, 30th April.

FIG. 77.—Patient aged twenty-three years; wounded by a piece of shell, 1st November 1914. X-ray, 11th May 1916; a large cavity with a small orifice; no sequestra; rarefying osteitis of the epiphysis. Operation, 30th May. Still a sinus in September.

or even heal, this results almost always merely in the formation of a new abscess, which again reopens the former track.

Only small, straight, sharp-pointed sequestra can emerge spontaneously in this way, passing first from the bone cavity through a cloaca into the track of the sinus, thence along the track to the exterior. A

SEQUESTRA LYING OUTSIDE THE CAVITY.

FIG. 78.—Patient aged thirty years; wounded by a piece of shell, 6th May 1915; never been operated on. X-ray, 9th April 1916; spontaneous issue of a sequestrum followed by a rapid cure.

FIG. 79.—Patient aged twenty-three years; wounded by a bullet, 22nd August 1914. X-ray, 18th April 1916; a large sequestrum removed, 5th May; healed by 1st September.

knowledge of pathological anatomy will render clear the mechanical conditions necessary to allow of this natural elimination (figs. 78 and 79).

Those parts of the limb, especially the lower limb, distal to the lesion often remain for a long period

œdematous, the skin cyanotic, the superficial veins engorged, and the muscles atrophied.

The function of neighbouring joints suffers in two different ways :—

1. Those joints immediately contiguous to an inflamed epiphysis either become involved in the spread of the inflammation, the result being an arthritis which may or may not suppurate, ending in fibrous or bony ankylosis, in good or bad position, or else become restricted in their range of movement by the enlargement and irregular shape of the end of the bone.

2. Those at a distance from the lesion may become fixed, often in a bad position, because of progressive fibrosis or contracture of muscles, because of the adoption of a bad position that has not been corrected sufficiently early, because in some cases of insufficient immobilisation, in other cases of inadvisable or too prolonged restriction of movement. This is specially the case in the joints of the fingers and of the foot.

This stiffness and ankylosis of joints, atrophy, contracture, and adhesions of muscles and tendons, form the subject-matter of a subsequent chapter. In conjunction with the common shortening of the affected limb they constitute the chief causes of functional disability. If it were not for these, and for the acute attacks of inflammation to which such cases are liable, this condition—chronic osteitis with persistent sinus—would be accompanied by but little pain or disability.

The occasional exacerbations of inflammation are usually accompanied by a certain amount of fever. But as a rule the temperature and general condition

of the patient remains fairly satisfactory. But such patients are often rather pale, and frequently their evening temperature may be slightly raised. One can hardly say that they are suffering from chronic septicæmia, but some slight degree of such a condition is usual in those who suffer from chronic suppurative lesions.

Course, Duration, and Termination.—In practically all cases the sinus dates right back to the early stages of the disease ; the early acute inflammation subsides, the area of osteitis becomes circumscribed, and the suppurating track settles down to form a chronic sinus which will persist until the focus of bone disease has been adequately and radically dealt with.

Where the seat of fracture has originally been exposed in a widely open and suppurating wound complete healing of the soft parts, even temporary, hardly ever occurs. Secondary sinus formation occurs only in those cases of fractures by bullets that at first appear to be uniting without suppuration, but in which sooner or later, especially where the foreign body has been retained, there appears a recrudescence of infection and inflammation. This is analogous to what occurs in the track of a bullet through soft parts in which has remained some fragment of clothing ; it is even more closely analogous to those simple flesh wounds in which a foreign body apparently long since " healed in " suddenly gives rise to a severe acute inflammation.

During the time when the wound of the soft parts is gradually contracting down to form a sinus the bone itself continues to increase in size until, in three to four months, union having taken place, it reaches what is practically its maximum, although, even

then, it still has a tendency to undergo a further slight but slow increase.

The condition at this point is that which I have described as typical of the disease; but on to this background of chronic inflammation we must add the occurrence at variable intervals of time of acute and subacute exacerbations, when the skin around the sinus becomes the seat of acute lymphangitis or even erysipelas, or when, in and around the bone, develop painful inflammatory swellings that in time either gradually resolve or else proceed to suppurate; in the latter case abscesses form of considerable, and sometimes of enormous size, with great quantities of pus of a foul odour accompanied by high fever and a serious general condition. In other cases an abscess forms slowly and without much pain or elevation of temperature; a diffuse induration—the skin over it showing a slight red blush—appears surrounding a part or the whole of the thickened bone; this after some time becomes soft and fluctuating at one spot, and unless incised and the pus evacuated, bursts and soon develops into another sinus; sometimes, however, on incising such a swelling one finds nothing but granulation tissue with a little sero-purulent or glairy fluid. These abscesses will be found to lead either to a perforation in the bony wall of a cavity, or simply to a bare surface of bone softened by rarefying osteitis

For around the infected cavity this rarefying osteitis does not cease to progress. If left to itself, free from surgical intervention, it is not only incurable but even destined to make considerable headway. If, on the other hand, a sufficiently radical operation be performed at the suitable moment, final cure is the rule; it may be slow, and obtained only by long and careful

after-treatment, and even only after secondary operations. It cannot be too often repeated that cases of final healing following spontaneous elimination of sequestra—though such may occur with a superficial free sequestrum—must in practice be regarded as non-existent.

Even after cure by operation the patient's troubles are not necessarily ended; in the most favourable cases the existence of a large, densely adherent scar forms a very real disability, especially in those cases in which the scar, covered with but a thin layer of epithelium, remains adherent to the subcutaneous surface of a bone. Here, to a greater or less extent, it is constantly exposed to the danger of re-ulceration. Again, and worst of all, small foci of infection that may lie latent, deep in the bone for months or even for years, are liable to become active and form new abscesses and sinuses; it is true, however, that these foci are usually of but small dimensions.

This is in full accordance with the classical course of the spontaneous osteomyelitis of childhood, with the history of its chronic sinuses, with the revival of its activity, extending—especially when present in the lower femoral epiphysis—sometimes over the whole period of the patient's existence. Rational surgery is then of very great value in the treatment of this disease, but cure does not invariably follow, and in many cases one can never be certain that final cure—in the real scientific sense of the word—has been attained. In diffuse osteomyelitis, spontaneous or traumatic, the surgeon can only consider that the pathological process has ceased for the time being; one can never definitely affirm that it has been finally eradicated.

Regarded from this point of view, the osteomyelitis following the compound fractures of civil surgery always seemed to us on the whole less serious than the osteomyelitis of adolescence. Since the advent of antiseptic surgery we have only rarely seen in compound fractures acute diffusion of the infection up and down the shaft of the bone and the production of extensive necrosis; we have been accustomed to find only small localised sequestra lying in compact mass of new bone that healed readily and finally after their removal. In the compound fractures of this war, however, these serious complications have re-appeared with a surprising frequence; the older surgeons have renewed their experience of, the younger have seen for the first time, these interminable after-effects of a diffuse traumatic osteomyelitis, associated at its commencement with an extensive inflammation of the soft parts, which may be more or less infiltrated with gas and gangrenous.

All this is due to many factors, some of which are inevitable, *e.g.* the extent and severity of the bone lesion, and the laceration of the soft parts; the inevitable original infection of the wounds contaminated by projectiles and by portions of extremely dirty clothing, the impossibility of securing for these wounded the treatment they so urgently need right in the front line at the time the wounds are sustained. But it is necessary to state that it is due in part also to a defect of organisation, to the frequent absence of an experienced surgeon from that surgical station at which, after an inevitably hasty dressing and removal from the dressing station, the wounded man ought really for the first time to be thoroughly examined and efficiently treated.

CHAPTER III

THE TREATMENT OF CHRONIC TRAUMATIC OSTEOMYELITIS

The treatment of bone sinuses resulting from gunshot wounds has too often been entrusted to physicians who, out of touch with surgical pathology and the operative inferences to be drawn from the study of it, have allowed the lesions to stagnate and grow worse. I have seen, too, many patients with chronic sinuses who, after being discharged from hospital with good union in a fracture which has been very well treated from the outset, are allowed to remain for months, sometimes for a year and more, without anyone dreaming of submitting them to further operations : some have had absolutely no treatment at all, others have been treated by hydrotherapeutic or physiotherapeutic methods, which is much the same thing, only often worse in its effects.

In many institutions " for the slightly wounded " treatment is restricted to the insertion of small drains or tents into the track of the sinus—small, straight, long strips of gauze having nothing in common with the methodical plugging of a widely open bony cavity to ensure its healing from the bottom. The small strip introduced by a probe scarcely dilates the track,

does sometimes reach as far as the bone, but never enters the cavity itself. The day when on removing the strip in order to change it a small sequestrum is found at its end, great joy is experienced and great hopes indulged in; but the sinus goes on as before, becoming neither smaller nor larger. Where there are any deep sequestra enclosed by sub-periosteal bone formation, this is a useless and deceptive method of treatment. And where there are none but merely a limited area of bare bone, it is harmful; the introduction of the foreign substance merely keeps up the suppurating track, just as in former days the issue peas kept up the ulceration produced by the cautery or the tent kept open the seton. When I see a patient with a chronic sinus with but little discharge, in whom the bone is neither enlarged nor tender, nor shows on skiagraphy any area of rarefaction, the first thing I do is to order the removal of the gauze drain, and in more cases than might be expected I see sinuses that have been kept discharging for months heal in a few days.

An official circular—which I published in the *Bulletin de la Société de Chirurgie* in April 1915—recommended the soaking of the gauze drain with a polyvalent serum obtained by MM. Leclainche and Vallée by immunising horses against aerobic and anaerobic bacilli of various sorts (staphylococcus, streptococcus, bacillus coli communis, bacillus pyocyaneus, bacillus perfringens, etc.); and a writer whose name I prefer not to mention, although Roux has presented him to the "Académie des Sciences," has affirmed that by this means excellent results have been obtained *without danger*, that the serum at first quickly produces signs of acute inflammation and the

suppuration appears to be increased, but that as a matter of fact the sinus discharges an abundant leucocytic exudate instead of pus, sequestra and foreign bodies are mobilised, the gauze becomes entangled with them, and they come out with it or else are easily removed with forceps, the result being usually a rapid cure.

On *a priori* grounds these statements would appear strange to surgeons who know exactly what an enclosed sequestrum and a bony cavity mean. Judging by results—a point of view which is of greater value—I have seen patients thus treated who have had later in order to be cured to submit to an extensive operation, and, above all, Mouchet has supplied us with certain details which the writer had thought fit to omit from his circular.

1. The reopening of sinuses amongst the wounded, who have been discharged as healed, is frequent: the time that has elapsed before reopening of the sinus has often been no longer than that of the journey from Beaugency to Orleans, which did not take very long even in D'Artagnan's time.

2. Lymphangitis and even erysipelas have occurred in almost 50 per cent. of the cases.

3. Very often the suppuration has been profuse and foul, with sloughing of the wall of the sinus. What takes place in the soft parts also takes place in the bone, where necrosis of the superficial parts or caries in the epiphyses occurs to a much greater extent than before, and even sometimes provokes a suppurative arthritis.

4. All this does not happen without a serious affection of the patient's general condition—a septicæmia that may even prove fatal: and certain deaths

are accompanied by clinical signs that point to a poisoning of the bulbar centres.

It is unfortunate that the results have not realised the hopes of the inventors and the assertions of the practitioner who used it, for it would have been, as Delbet said, " excellently polyvalent." And also, as I remarked to Delbet, the list of bacteria against which it is effective, although already long and varied, ends with " etcetera," in the same way that the heathen, in order to propitiate all the divinities, raise their altars to " The unknown God."

These unfortunate occurrences are due to irresponsible and incompetent scribblers—although, perhaps, medical men—for the serum of Leclainche and Vallée seems to be remarkably efficacious in preventing gas gangrene, as these workers had shown even before the war. It is a pity that the work of two such eminent scientists should have been thus compromised.

Physiotherapy has of course had pretensions as regards the cases we are now dealing with. I set aside for the moment manipulations, massage, methods which have rightly or wrongly been used in the treatment of the atrophy of muscles, the stiffness and deformity of joints associated with compound fractures. I shall deal later with the indications, and also with the frequent disadvantages of this form of treatment whilst there exists an open sinus or even a mass of exuberant callus, the possible origin of a recrudescence of inflammation. But the one constant objection that has developed during the last ten years against physiotherapy is that its practitioners seem determined to find agents suitable to the treatment of chronic sinus as a disease in itself. I have seen

patients with chronic sinuses without joint disability sent to these centres for treatment by physical agents.

It is especially to sunlight that physiotherapists have turned, believing that its action could lead to the expulsion of sequestra, and thus to final healing. Instead of the sun, some have employed radiant heat. I know that heliotherapy is fashionable at present, and that to doubt its universal power is to court unpopularity. I had, however, doubts about it before the war, and I have them still. Exposure to sunlight and to radiant heat are excellent means of treating certain chronic wounds and certain ulcers with a thin serous discharge. Heliotherapy in the case of a tuberculous sinus of a bone or joint origin often results in a decrease of the chronic inflammatory infiltration of the soft parts, which are thereby rendered more supple, and in a rapid healing of superficial sinuses. It seems to me to have a real sterilising action on the mixed pyogenic infection, which at this stage is so often a serious complication. But it certainly seems to be absolutely incapable of eliminating sequestra, tuberculous or otherwise, or of closing up an osteomyelitic cavity. We all know the phenomenon of spontaneous discharge of sequestra from a cavity, and understand the anatomical conditions that render it possible; no one has proved that it is any more frequent after heliotherapy.

It was traditional in the older treatises to claim a peculiar virtue for mineral waters in the cure of bony sinuses, and naturally the modern prospectuses of these establishments still maintain this claim. Amelie-les-Bains is the principal military centre for balneological treatment, which seems to have a certain range of usefulness in stimulating slow-healing wounds, but

which it is most certain is quite useless if there be sequestra, or even a bone cavity without sequestra. Granted that it might be useful to try this treatment when a granulating surface persists and refuses to heal, *e.g.* a large gutter cavity in the tibia, still I must add that in my own practice of civil as well as of war surgery I have not yet found it necessary in any case.

As a matter of fact, all these auxiliary means are contra-indicated when there are sequestra or cavities in the bone. The only treatment that should be advised is operative. The operation will be a simple one, followed by a rapid cure if the sequestrum is superficial and leaves no cavity in the bone behind it but a small and unimportant one, and in this case the cure will be much more rapid than by those non-surgical methods that are supposed sometimes to have contributed to the spontaneous expulsion of the dead fragments. The operation will be difficult, complicated, and the final healing delayed if there are sequestra buried deep in the bone, which leave behind a large cavity with thick walls; but in a case like this all the other methods, although one may have been inclined to believe in them, would have been perfectly useless.

When a sequestrum has come out spontaneously, or what I repeat appears to me to be the same thing—after-treatment by one of these agents—it should be possible to judge from the size of the bone or from the appearance of an X-ray plate (remembering, however, the reservations that I have made in this connection) whether there is any chance of its having been single and superficial, in which case the healing up of the soft parts should take but a few days. But

these spontaneous eliminations of small fragments are almost always of no curative significance—large pieces still remain inside the bone—and even supposing that these too could be discharged in the same way, there still remains the pathological condition of a sequestral cavity which, if even of only moderate size, will never spontaneously fill up and heal. This at once brings us to the realisation of the fact that the operation which should be performed is scarcely ever a mere scraping or curetting. These are words that have become popular and of common use to such an unfortunate extent that they are apt to make one think that they refer to an easy, slight operation, the performance of which lies within the capacity of anyone, that consists merely of enlarging the sinus and scraping with a sharp spoon the opening in the bone.

It was a great mistake among those who, in peace time, prepared for war surgery, and even among those who directed it during the first few months of this war, to have neglected the lessons of the past, and to have imagined that because of " humane " projectiles and of antiseptics late inflammatory phenomena in compound fractures would not occur, or at least would be of but little importance. Hence the attention given to the treatment of sinuses was too often far from sufficient—a gauze drain in the sinus, at intervals a scraping with a sharp spoon, sometimes performed even without an anæsthetic.

I am not even sure that certain professional surgeons, disdainful of what does not concern the visceral cavities of the body, have always been well versed in the details of the pathology and surgical treatment of traumatic osteomyelitis. They know

all about intussusception and the importance of operating on it, but often they seem to think that the mere removal of sequestra is sufficient—an idea that is essentially wrong.

Certainly we should before all things remove sequestra; this alone suffices if the cavity left is small and the sequestrum has been superficial. But in the great majority of cases this alone is quite insufficient, the cavity in the bone still continues to suppurate. What is required is a surgical procedure that will obliterate this cavity once for all. The necessity for the removal of enclosed sequestra by enlarging to the necessary extent natural openings in the walls of the cavity—cloacæ—or by actually cutting away sufficient of the wall itself, will be readily understood after what we have said regarding the pathological anatomy of chronic osteomyelitis. As to the treatment of the cavity itself, various methods are in use. It will be necessary to explain the principles of these, and to point out the details of their application.

Under the influence of the pioneer researches of Ollier free sub-periosteal resection of bones has been performed, especially in the osteomyelitis of childhood. The periosteal cylinder if preserved was to lead to regeneration of the bone. This osteogenesis, however, proved less invariable than had been supposed even in childhood, still less so in the adult, hence this practice has little by little been given up.

Sédillot was quite right when he fought against Ollier for the mere excavation of diseased bone as opposed to the complete resection of bone in chronic osteomyelitis. We can no longer now collect those museum specimens which were so interesting at the time when they were obtained, in which the whole

former shaft is seen lying as a sequestrum inside a case of new sub-periosteal bone. Sédillot was in the right in holding that it would have been far better had Larghi and Borelli merely removed the sequestra, rather than have practised total sub-periosteal resection for deep necrosis ; he was certainly in the right to maintain the greater field of usefulness of the more limited operation. It is enough to read Ollier's *Traité des Resections* to be convinced that little by little, for the extra-articular lesions considered here, the Lyons master was not long before he himself came to follow the path on which we are to-day. If he insisted on the rôle of the periosteum, he also ventured on studies from which to-day we have to borrow in connection with the healing of bony cavities with rigid walls. Let us consider any abscess of the soft parts, let us take, for example, a case where the abscess is kept up by the presence in it of a foreign body ; when this is removed at once the soft parts subside, the walls of the abscess come into contact, and healing of the cavity soon takes place. On the other hand, clean out as carefully as you like an abscess cavity with rigid walls, and it will heal only with its complete obliteration. This can be brought about in one of only two possible ways :—

Either it fills spontaneously by the abundant proliferation of granulations from its walls ;

Or it becomes filled by the entrance of neighbouring soft parts into it.

The Spontaneous Ossification of the Cavity.—"The radical operation in osteomyelitis," says Sédillot, "is one that by excavation of the bone completely removes all diseased areas and leaves only the healthy cortical or peripheral sub-periosteal layer of the bone.

By it the shape of the limb remains unaltered, muscular attachments to bone are spared, the periosteum is left intact, and formation of new bone takes place both from the deep surface of the periosteum and from the walls of the excavated cavity."

Where the bone that remains is healthy, this production of new bone is closely analogous to the process of repair in fractured bone, that is to say, the cavity fills with blood-clot, which, gradually replaced by mixed tissue elements arising by proliferation of the essential marrow cells alike of sub-periosteal and cancellous bone and of the medullary canal, ultimately becomes converted into bone, after having passed through an intermediate stage of conversion into cartilage.

In an experimental excavation involving, after careful elevation and preservation of the periosteum, merely the underlying layer of compact bone, very little blood is effused; this on clotting becomes rapidly absorbed, and the periosteum, sinking down into the cavity, soon becomes adherent, and only later from its deep surface deposits new bone. Hence no matter how shallow the original cavity has been, there always remains a depression in the bone to mark the place where the experiment has been made; in other words, the regeneration of the compact bone has not been complete.

Similar experiments have been carried out during the last fifty years by many different workers with the object of studying the repair of solutions of continuity artificially produced by saw-cuts in compact diaphysis or in cancellous bone, sometimes involving only the superficial layers, sometimes penetrating deep into the medullary cavity, in certain

cases accompanied by careful preservation of the periosteum, in others by more or less extensive removal of it. All such experiments have served to demonstrate the osteogenetic properties of granulations arising alike from the deep surface of the periosteum, from the Haversian canal systems, and from the medullary canal. I am not going to insist specially on this property, to-day universally recognised, of the sub-periosteal layer, nor to concern myself with the theoretical discussion as to whether this layer really forms the deep layer of the periosteum or the most superficial layer of the bone. The practical fact is sufficient for us that when the periosteum is stripped, pathologically or by surgical means, this layer follows the fortunes of the periosteum. I will remark in passing, however, that it is largely this new bone of sub-periosteal origin with which we are concerned in the performance of this operation for the cure of osteomyelitis; it is sub-periosteal new bone that requires removal, that is found enclosing the sequestra formed by the necrosis of the original shaft, that forms the walls of the cavities and tunnels full of pus and granulations that require excavation and obliteration, so that in such cases the whole process of repair of the bone lesion is due almost entirely to the activity of this layer.

These experiments have given results which do not differ from those which were carried out by Ollier himself, and formed the starting point of all our knowledge of the process of repair of bone.

The results, thanks to the discovery of antisepsis and later of asepsis, have been improved, but only in the direction of greater frequency of success, and because we can now eliminate the results of infection of the experimental wound. This is specially true

as regards the aseptic organisation of the effused blood-clot, to-day so well known; further on we shall see what surgical inferences can be drawn from this.

This organisation of clot, the importance of which—in the repair of compound but uninfected fractures—was long ago proved by Lister, results experimentally in the complete filling up of small bony cavities produced by excavation, over which immediate suture of the periosteum and soft parts has been carried out. In the course of a few weeks the bone, the solidity of which has not been interfered with, returns almost completely to its former state, only a small depression remaining to show the site of the operation. A similar result follows the cutting of a straight groove along the long axis of the bone. Blood fills the cavity left by the operation, forms a matrix which is replaced by granulations that become fibrous, then cartilaginous, and then finally ossify.

Such granulation tissue besides possesses a certain power of contraction which, by drawing the walls of the cavity towards its centre, diminishes to some extent the size of the cavity. This is of little practical significance except in special cases, as in the obliteration of a cavity in the jaw after extraction of a tooth. In this case, however, there comes into effect an important absorption of the walls of the cavity that allows of the collapse of the neighbouring soft parts. But in real surgical cases such an absorption of the walls is absent or is insignificant. It is true that Sédillot in the early stages of his research believed that such took place in the thinned-out sub-periosteal layers of the bone, leading to an increase in the elasticity of the walls that resulted in a concentric decrease in the size

of the cavity; at the same time he considered that the periosteum was partly drawn inwards by retraction of the granulations in the cavity, partly pressed in by the weight and tension of the overlying soft parts. Perhaps Ollier was wrong when he denied absolutely the existence of such processes, but he was right in the sense that the surgeon has no right to depend on their occurrence.

The practical fact remains that if a cavity of some size has been excavated in a bone, the rigidity of its walls is such as to render all possibility of their collapse quite negligible; and as, on the other hand, the ossification of the granulations from within is always an exceedingly slow process, complete repair of the cavity becomes most difficult of realisation. The greater the size of the cavity the more difficult does this repair become; indeed it increases not in arithmetical but in geometrical progression according to Ollier, but one can hardly, in this connection, give their real mathematical value to these words.

In the repair of such cavities, as in all questions of bone surgery, the age and state of the general health of the patient are of great importance; the younger the patient, the more chance is there of spontaneous ossification, and in the case of children one would attempt conservative measures which one would not dream of considering in the case of adults.

Some writers have attempted to transfer these physiological principles to the realms of surgery, and to apply them in the treatment of bone cavities of large size; they just apply a tourniquet and excavate the focus of disease; the soft parts are then closed by suture and the tourniquet released, so that the cavity fills with blood. The clot will become organised and

serve as a basis—gradually undergoing absorption the while—for a real *osteogenesis by substitution.*

This is most brilliant surgery, but it demands an absolute asepsis. Now *the complete disinfection of such a cavity in osteomyelitis is quite impossible*, and all attempts to obtain this ideal result by this method have failed. I am not ignorant that Bier has described an osteoplastic removal of sequestra in superficial bones like the tibia, which is an extreme example of this type of operation, and for which he makes great claims. Two transverse incisions going right down to the subcutaneous surface of the bone and extending a little further outwards than the crest of the tibia are made corresponding to the upper and lower limits of the diseased area ; a third vertical incision is then traced, joining the inner ends of these two transverse incisions. Along these three sides of the rectangle so formed the bone is divided from without inwards ; the chisel is next inserted into the vertical cleft in the bone, and with it the outer surface of the shaft divided from within outwards, the periosteum over this surface, however, being respected. In this way a large osteoplastic flap is cut of the shape of the lid of a snuff-box, which is then levered up from within outwards ; after the sequestra have been removed and the sequestral cavity cleaned out, this flap is replaced into its original position, no drainage being used.

I have never tried this method, and I shall be surprised if ever I come to do so, for it has always seemed to be most irrational to leave blood-clot thus enclosed in an inevitably infected dead space. I think that if its author has employed it he can have declared himself satisfied with it only by viewing the results obtained in too favourable a light.

Attempts have been made to render the cavity aseptic by *packing it with antiseptics prior to allowing it to fill with blood-clot.* In turn powdered iodoform, iodoform-glycerine emulsion, the subnitrate of bismuth, and salicylic acid have been recommended. The results have not been good; apart from the occurrence of cases of iodoform poisoning, it did not take long to prove how unreliable and uncertain chemical agents are in rendering aseptic an already infected field of operation. This fact, which holds good for all operations, applies especially to where a rigid incompressible cavity is left in which blood-clot mixes with the antiseptic and forms so important a part of the obliterating mass.

Since the attainment of absolute asepsis remains thus uncertain whatever antiseptic be used, the less blood allowed to accumulate in the cavity the better. It is on this account that most processes of "substitution" aim either at packing the cavity as tight as possible, or at filling it with substances that by accommodating themselves absolutely to the irregular shape of the cavity succeed in its temporary complete obliteration.

A. Methods in which the Cavity is packed with Organic Materials

Whatever substance is employed, it is quite evident that blood will fill in the interstices; but also it is evident that this blood may be reduced to a very small quantity, merely thin layers, which on coagulation serve to unite the bone to the foreign substance. The substances used are of an organic nature, but absorbable. They are divisible into two classes:—

1. Sponges and various organic substances other than bone.
2. Dead bone, decalcified or not.

1. *Sponges and Non-bony Organic Substances*

We will take the packing with sponges as the type of this method of treatment, because it was the first recommended, and because under the very bad name of sponge-grafting it has been used in exact experimental work as well as therapeutically.

In the original technique of Hamilton (1881) Turkish sponges were used; they were cut into thin slices, decalcified by immersion in weak hydrochloric acid, washed in an ammoniacal solution, and kept in 1 in 20 carbolic acid. The practice of Duplay and Cazin, who allowed the sponge to retain some of its siliceous spicules, is of no particular interest. The only really important or vital point was to assure the absolute asepsis of the sponge, and for this one had to trust to prolonged immersion in antiseptics. With Hamilton's technique failures were frequent, and the only certain method of assuring the absolute asepsis of the sponges is to cut them into variously shaped fragments and submit them for half an hour to a temperature of 120° C. in an autoclave. This makes them a little gelatinous, but this is rather an advantage than otherwise. This extraneous substance having thus been rendered aseptic, all will go well if the cavity into which it is packed is also aseptic—a condition easy to realise experimentally. After a first, but temporary, very tight packing in order to stop hæmorrhage, the final packing is carried out less firmly, so that when the sponges swell the cavity will not be

over-distended; the periosteum and then the soft parts are closed by suture.

In experiments on the rabbit, by the fifth day the fragments of sponge were so firmly united to one another and to the bony walls that a cross-section of the cavity with a saw failed to displace any of the fragments, and in such a cross-section the respective limits of sponge and bone were no longer to be distinguished. By the fiftieth day sponge was no longer to be detected by the naked eye, and bony repair had proceeded at a rate far greater than in the control animals in which the bony cavities had been left empty.

Under the microscope an intense proliferation of cellular elements was seen to occur; from the fifth day onwards these invaded the interstices of the spongy network, and little by little replaced it. This latter became absorbed, whereas the newly formed granulation tissue became ossified, and by the time repair was complete there remained in the new foundation of bone only some few spicules of silica of no practical importance to remind one of the previous presence of the sponge.

Other organic materials have been used by various workers, and the results of each have been compared with that obtained with sponge by Duplay and Cazin. Iodoform and aseptic gauze give very similar results; silk and cotton are not so easily penetrated by the proliferating cell elements, and cotton even becomes encased by fibrous tissue; aseptic catgut is also less easily penetrated but more easily absorbed than sponge, but its greatest defect is the uncertainty of its sterility. It is unnecessary to do more than mention such substances as muscular fibres of the calf, the sub-mucous

coat of the pig's intestine (Halsted), filaments of fibrine of bullock's blood treated with corrosive sublimate, iodoform in alcohol, or ether—substances all of which being difficult to prepare and to sterilise with any certainty, possess besides no counterbalancing advantages over the previously described materials, and none of them have gained any permanent place in surgical practice.

2. *Dead or Decalcified Bone*

When the insertion of these substances, absorbable and favourable to osteogenesis by substitution, was first thought of, special attention was paid to the use of fragments of bone, as it was considered on theoretical grounds, which, however, turned out in practice to be quite untrue, that the Haversian canal system of bone would prove a useful path already prepared for penetration by the elements of the future new bone, that the already existent structure of the bone would thus be specially favourable to the building up of new bone tissue.

In 1889 Senn thought of decalcifying the bone to make it more malleable and more easily cut into pieces, whilst still preserving its supposedly advantageous canalicular structure.

The bone intended for decalcification is taken from the compact portions of the tibial or femoral shafts of the bullock. The hard bony tissue alone is used, the periosteum and marrow being removed; it is cut up into small chips or else into much larger fragments, according as one is going to make use of one or other of two different methods of implantation. These pieces are then placed in a 1 in 10 solution of hydro-

chloric acid, which should be changed every day. An eight days' immersion will produce sufficient decalcification, but for the completion of this process about four weeks is necessary.

The bone is now soft and easily cut. It is washed in plenty of water to remove all excess of acid, or else immersed in a 1 in 500 aqueous solution of corrosive sublimate. It is kept either in weak potash solution, then for forty-eight hours in 1 in 500 aqueous solution of sublimate, or else in iodoformed ether (1 in 10).

Before being used the decalcified fragments are wiped dry, then plunged for a short time into alcohol, then into an aqueous solution of sublimate 1 in 2000, or in 1 in 50 carbolic acid, and finally they should be dried with the greatest care so as to render them absolutely free from the least trace of alcohol, in the presence of which they would swell when packed into the bony cavity with a force sufficient to burst the stitches.

The excavated cavity is prepared for the reception of the decalcified bone chips by the most careful removal of all dead or diseased bone ; it is then wiped clean, thoroughly flushed out, and sprinkled with iodoform ; efficient and complete hæmostasis will have been provided for by the preliminary application of an Esmarch's bandage When it is quite dry the bone implantation is carried out, the chips being inserted and pressed down so as to leave no dead spaces.

The wound is closed without drainage. The first dressing should not take place until the 12th or 14th day, and after that only at the end of two or three weeks if primary union has occurred, sooner, and as often as necessary, if there has been suppuration.

When this is profuse it will probably be necessary to remove the stitches and also the bone packing, the case thus resulting in failure; another attempt may be made later when the discharge has again ceased.

The process of repair in successful cases has been studied in the rabbit and in the dog by Ochotin and by Buscarlet. Placed in the cavity and surrounded by a capsule, the decalcified bone first produces inflammation of the bony walls, whose essential elements proliferate and soon commence to eat into the decalcified bone—a process that takes place to a greater extent from the medullary than from the periosteal wall of the cavity. This is indeed almost the same process as occurs in the case of a living bone graft that has "taken," except that in this latter case a definite circulation is established in the graft which, until the time of its reabsorption, causes it to take a definite place in the life of the tissues.

Absorption of decalcified bone takes place sooner than does that of dead bone or of living graft. It is even said that it takes place so rapidly that the final result is merely a fibrous and not a bony cicatrix, but it is easy by decreasing the length of time of its initial immersion in hydrochloric acid to render the process of absorption less rapid.

In the hands of Senn and of his pupil Mackie good results have followed the employment of his technique, especially in the case of cavities as large as hazel-nuts or walnuts, but these are too small to convince one of the practical utility of the method.

In other hands most attempts have failed. Buscarlet, with his master Le Dentu, however, considers that it is of some advantage in cases of large cavities, over which it allows the suturing—instead of packing

—of the soft parts, so that in young people the period of healing is shortened.

This temporary support is of no use, however, if the patient is old or if the periosteum has been sacrificed, but in most excavated cavities it is preferable to the use of living bone. This latter, on the other hand, is of more use in the restoration of a whole bone, when the provisional support for the ultimate ossification must last for a long period.

Incompletely decalcified bone has the advantage of being more slowly absorbed than a massive graft; also, it brings to the centre of active repair calcareous material necessary for the process.

The difficulty of preparation and sterilisation of the substances to be implanted, the almost inevitable persistence of unoccupied dead space in which blood accumulates, are the inconveniences of the method.

In place of decalcified bone, Barth has proposed to fill the cavity with the ashes of incinerated bone, Grosse with a mineral powder (phosphate of lime 85·6, phosphate of magnesium 1·75, chloride of lime 3·5, carbonate of lime 9), on the theoretical ground of furnishing elements necessary to the building up of new bone. All these have merely resulted in persistent suppuration, with the ultimate discharge or removal of the implanted substances.

B. Methods in which the Cavity is filled with Emulsions and Pastes of an Inorganic Nature [1]

These methods are the only ones that allow of absolute obliteration of all dead space in the cavity,

[1] This procedure is commonly called "bone stopping or filling." The only real bone filling consists in securing (as in dentistry) the complete

the substance used fitting closely to the walls of the cavity during their application; all hæmorrhage into the cavity must be prevented by the use of Esmarch's bandage. Such substances as have been used are aseptic, or so mildly antiseptic as to overcome as far as possible the existing infection of the bone, but at the same time avoid compromising the vitality of the osteoplastic elements.

I pass in silence over pastes of plaster, cement, etc., and commence at once with the antiseptic mixtures that set to a solid. Under the name of *iodoform paste* they have been much in evidence during the last twenty years, although perhaps their usefulness has been over-estimated.

In 1896 P. Reynier and Isch-Wall, in order to avoid reinfection of the blood-clot, recommended pouring into the bone cavity an antiseptic that would set to a solid—*salol iodoformé*. Salol melts at a temperature slightly greater than blood-heat, and in its melted form it becomes capable of dissolving iodoform; at 98·6° F. the mixture solidifies into a vitreous mass. The melting point of the mixture is sufficiently low to allow of its being poured in the liquid state into the cavity, and on its solidification at body temperature the smallest irregularities of walls of the cavity become obliterated. The cavity should be first prepared successively with iodoformed ether, chloride of zinc, and the thermo-cautery—the antiseptic power of the iodoform and salol mixture is expected to destroy any remaining bacteria;

obliteration of a bone cavity with a malleable foreign body (originally lead, then various metals, then non-metallic bodies) destined not to be absorbed, but to become encysted. This has been done in long bones with various substances (copper amalgam, lead, gutta-percha, cement). In osteomyelitis, failure is invariable.

complete closure of the soft parts should then be performed. It should be added that the size of the cavity should not exceed that of a nut.

It is sufficient to mention attempts made with such substances as naphthalene, a formalin-gelatine mixture, and of paraffin.

The antiseptic mixture invented by Neuber is a real paste, having the following composition: 10 grams of flour are soaked in a little cold distilled water; whilst this is being stirred 200 grams of a boiling solution (12 in 100) of carbolic acid and then 10 grams of powdered iodoform should be added. This iodoform paste is poured into the cavity after it has been thoroughly dried out, and the soft parts then sutured. The tourniquet should then be removed, and blood becomes mixed with the paste; healing by first intention occurs in two-thirds of the cases. Before filling up the cavity it is necessary to change all instruments, swabs and towels, etc., that have been used up to this stage of the operation: the surgeon and his assistants should also resterilise their hands. The observance of this technique is absolutely necessary if reinfection of the cavity is to be avoided. The soft parts on being sutured should not be subjected to any tension. Since this method results in a considerable intermixture of blood with the obliterating medium, it really forms an intermediate between the method of Schede and those in which are used real pastes made of substances that become quite solid.

Since 1898 Mosetig Moorhof has studied the action of an *iodoform paste* which he has made famous. It is intended to obliterate the cavity completely, and to be itself subsequently absorbed; hence it comes

into the category of substitution processes. The formula of Mosetig Moorhof is as follows :—

Powdered iodoform . .	60 grams.
Oil of sesame . . .	40 ,,
Spermaceti . . .	40

Equal parts of the last two constituents are melted on a water-bath in a cylindrical glass vessel, this results in a clear oily liquid, which must now be filtered. The powdered iodoform is then added and well stirred in, and when the whole is of a uniformly yellow colour it is removed from the fire. During cooling up to the stage of consolidation it should still be kept stirred; solidification takes place between 45° and 50° C., and the glass vessel containing it should then be covered with a sterile lid. It should again be melted on the water-bath just before use, and arrangements should be made that the outside of the glass container should be sterile, so that the surgeon can take it and pour the liquid from it directly into the bone cavity. Warmed thus on a water-bath it is not hot enough to damage the walls, to which on solidification it accommodates itself absolutely.

Careful preparation of the cavity is of the utmost importance; it is quite useless—although almost a classic routine—merely to scrape with a spoon and then to pour in oil or glycerine that is then evaporated *in situ* by the application of the thermo-cautery. For the four days preceding the operation the skin should have been regularly disinfected by the liberal use of soap and water, alcohol, and ether, and by constantly applied wet antiseptic fomentations. The bone is approached by incisions through healthy skin,

the cavity is opened for the removal of sequestra, and then with the chisel, or better with a burr, all the diseased or suspicious parts are excavated. One should stop short only when well into healthy bone.

The cavity should be perfectly dry, so that the mixture can adhere everywhere to the walls quite perfectly, hence the necessity for the use of the tourniquet wherever possible; even with it absolute hæmostasis in the cavity is often difficult to obtain. After having irrigated the cavity with 1 in 100 formalin solution so as to wash away the bone dust and débris produced by the burr, the cavity should be swabbed out as dry as possible, small points exuding blood being touched with adrenalin or oxygenated water, the preparation ending with the thorough drying of the cavity by means of currents of cold and hot air. If the use of a tourniquet is impossible, as in the shoulder and about the hip, the complete and necessary hæmostasis of the cavity will be a process that will test the surgeon's patience.

Into the cavity thus prepared the liquid should be poured a little at a time, the position of the limb being constantly changed so that every crevice and recess is completely filled. Solidification should be allowed to occur spontaneously, no attempts being made to cool it rapidly by ice or ether vapour. Only in the neighbourhood of joints is drainage necessary; in other cases the remains of the sinuses which have been carefully excised early in the operation suffice for drainage.

The various layers of tissue are then sewn over the cavity, including the periosteum, which on first approaching the bone should have been carefully elevated and preserved. After completion of the

dressing and fairly firm bandaging of the limb the tourniquet is released.

Mosetig Moorhof is very much against performing the operation in two stages, the filling of the cavity being delayed some days until its walls are granulating. He considers the attainment of absolute asepsis impossible under such circumstances, and that the paste should be used either in the first instance or not at all.

The first dressing should be performed on the tenth day; in cases in the lower limb the patient should be able to walk naturally in six weeks. If immediate healing is obtained, the iodoform mixture becomes gradually absorbed; if, however, suppuration occurs, more or less of the mixture is gradually extruded through the incision or through the openings of former sinuses; but it should not be squeezed out, much less deliberately removed. Histologically the process of substitution of this mixture is very similar to that we have described as obtaining in the other methods and procedures. Successive radiograms allow one to follow the progress of the absorption and ossification; but it must be confessed that on account of the relative opacity of iodoform to the X-rays, it is not always easy to be certain of the exact limits of the latter process.

On account of the fear of iodoform poisoning it has been proposed to replace the iodoform by some other antiseptic—Mosetig Moorhof himself experimented in this direction; but the other antiseptics used were found to give less satisfactory results, and as with his formula no case of poisoning had been known to occur, he concluded that such an alteration of composition was not justified.

Mosetig Moorhof was delighted with the results of his method; these were published by his pupil Damianos in 1904, and by himself in 1906. Up to this latter date he stated that he had in five years operated on more than 1000 cases with uniformly good results. This implies a truly extraordinary operative activity, since even in our largest special surgical clinics for children we meet with but few cases of large bone cavities requiring operation, and it is with such cavities only that we are concerned. As to the late results of his operation the writers gave no account, a fact that did not deter Rottenstein, however, from attempting to introduce the method into France. For, he argued, of the cases published in 1904 a good number dated back to 1899; if there had been cases of relapse, these would not have failed to return for further treatment. Mosetig would have operated again on these, and an account of such would have appeared in his tables of statistics; none such did appear, hence there could have been no relapses. I give this argument for what it is worth, but I confess it does not persuade me.

Again, according to Rottenstein, Mosetig Moorhof's results were very different from those of his followers, whose cases sometimes developed abscesses and sinuses, which Moorhof's never did. This he attributed to imperfect technique, especially to imperfect drying of the cavity.

A paste proposed by Fantino and Valan has the following composition :—

Thymol	1
Iodoform	2
Calcined bone ash	3

These writers advise a two-stage operation: first, to excavate the cavity, which is then scalded by evaporating a glycerine-iodoform emulsion *in situ* by means of the actual cautery; four days later, after a bacteriological examination of the discharge from the cavity which has been packed with aseptic gauze has proved its sterility, the cavity is filled with this paste. Especially successful in cancellous bone, this method yielded eight successes out of nine cases, small cavities being cured in three months, the large ones in seven or eight.

A eugenol paste has been used by Joüon (of Nantes), who has published his results.

Eugenol is an oily fluid, strongly antiseptic, and slightly analgesic, the active principle of the oil of cloves. Mixed with zinc oxide, it forms a paste which sets rapidly into a mass as hard as marble. This requires to be prepared actually during the operation, the eugenol being poured drop by drop on to the zinc oxide, previously finely powdered and sterilised by heating to 120° C. spread out on a plate. The paste must be kept continually worked up until it will no longer stick to the skin, when it should be kneaded into the cavity, working it in all the time so as to keep it homogeneous with a special instrument something like a burnishing tool. The cavity, which has been thoroughly excavated, is sterilised by touching its walls with pieces of gauze soaked in a saturated solution of carbolic acid in glycerine; absolute dryness and hæmostasis are indispensable conditions for perfect adhesion between the mortar and the bone walls. This substance does not become encysted by fibrous tissue, but is gradually absorbed and replaced by bone.

Delbet's mixture has the advantage of being capable of previous preparation. Its composition is as follows :—

Pure wax	50 grams.
Chloroform . . .	6 c.cm.
Tincture of iodine . .	6 ,,

The wax is melted on a water-bath, and then poured into a flask previously warmed to prevent too rapid solidification; the chloroform and tincture of iodine are added, and the flask tightly stoppered, and then shaken until its contents have become completely solid. (During this process the cork must be kept tightly in place, otherwise the chloroform vapour will dislodge it.)

This paste is malleable ; at ordinary temperatures it is easy to mould to the walls of the cavity, to which it adheres despite oozing of blood, and it acts directly on them as a hæmostatic. It seems to be the best of all for aseptic cavities, but Delbet soon gave up using it in osteomyelitic cavities, and at this I am not at all surprised.

As a matter of fact I have given careful attention for several years to every publication that has appeared on the treatment of chronic osteomyelitis by such means, with the practical result that I do not myself have recourse to them. In practically all cases (and even, I should add, when used in primarily aseptic cases) late suppuration occurs and the formation of chronic sinuses with ultimate discharge of the paste. Many cases have been reported in which a sinus persisted, very small perhaps, but such a statement does not mean much.

It has often been claimed that, although the results

of these methods have disappointed our hopes of securing primary union and aseptic absorption, these substances nevertheless constitute an excellent "internal dressing" which facilitates and hastens ultimate cure. Even this very modest claim is, however, not incontestable. From my study of numerous reports and observations I have received the impression that the effect of this "internal dressing," both upon the duration of healing and the ultimate cure, is exceedingly doubtful. Most cases of osteomyelitis of subcutaneous bones like the tibia, that are comparatively easy of approach, are cured by these methods, under conditions, however, that seem to be identical with those that obtain in the method I am going to describe. Similarly in extensive osteomyelitis of deep lying bones, of the lower end of the femur in particular, failures are common equally with the two methods.

The impressions that I had received before the war have not been modified in any way since. These methods of "filling" the cavity with pastes and cements, etc., have been frequently tried, but they have proved of doubtful value. I am not speaking of the failures that have come later into my charge; I should be told, of course, that naturally no one would send me the cases they have cured. But I am almost certain that cases of primary union without the extrusion of the extraneous matter have been quite exceptional, and that when such extrusion has occurred the mixture has done no good whatever.

C. The Technique of the Operation for the Obliteration of Cavities and Tunnels in Bone

I have always practised a wide removal of bone with free resection of one of the walls of the cavity, thus allowing collapse of the neighbouring soft parts, periosteum and muscles, into as complete and close contact as possible with the remaining bony wall; and it is the technique of this operation that I am goint to describe.

I never use a tourniquet in these cases.

1. The bone should be approached by a free longitudinal incision. This should be of such a length as to extend both up and down considerably beyond the limits of the bony cavity as proved previously by radiography; if need be this incision should be enlarged to conform to this rule during the course of the operation. Every bone has its "surgical" surface, over which one should incise the soft parts in order to approach it; no special attempt should be made, in planning the incision, to include in it the opening of one or more of the sinuses. Indeed the fistulous opening should form part of the incision only when it happens to coincide with the ideal site for incision that I shall describe later on; to attack a tibia, for example, from the back because the sinus opens there would be absurd.

The skin will often be found very tightly adherent to the bone, the muscles usually atrophied, discoloured, and fibrous; the periosteum, which will be greatly thickened, should be split from end to end of the incision. Then with the rugine the two lips of this should be raised and held aside with retractors so as to expose a third or even a half of this sur-

face of the bone, which will then appear rough and vascular.

This surface of the bone is sometimes soft and easily cut through with the curette; sometimes, and more often, hard and compact. Particularly is this the rule around a "cloaca," especially where this has been the result of a previous operation; here the new sub-periosteal bone is densely hard and eburnated; a sharp spoon will make no impression on it.

2. Hence mallet and osteotome are nearly always necessary in the second stage of the operation, which consists in opening up a large groove or furrow in the bone (nearly always newly formed of sub-periosteal origin) in order to get well inside the cavity that contains or has contained the sequestra. If an already existing opening presents, commence with this, chiselling so as, guided by the probe, to follow and open up the whole main cavity and its various prolongations.

If, however, there be no cloacæ presenting in the field of operation, then the bone must be chiselled in a direction parallel to the incision, first along the right side of its exposed surface, and then along the left; the upper and lower limits of the rectangular surface of bone that lies exposed must then be likewise cut through; the operator should first perform the upper—which is also the easier—of these divisions of the bone.

An experienced surgeon will know at once by the peculiar sound produced and by the sensation imparted to his hands exactly when the chisel enters the cavity in the bone; when the cavity has thus been opened from both sides, the surgeon, using the chisel as a lever, elevates *en masse* the whole wall of bone between the four lines of division.

The exact limits and size of the cavity that will require thorough excavation are now obvious; it will appear lined with granulations and containing pus; the sequestra are often immediately visible, but all prolongations and recesses of the original cavity should be carefully explored for others, not only with probe and sharp spoon, but also directly with eye and finger.

Sequestra lying in the midst of granulations should first be gently seized with a pair of forceps (I always use an ordinary pair of artery forceps) to ascertain whether they are freely movable or not. It is most important that any one that does not seem quite free, but has apparently an end or projection caught in one or other extremity of the cavity, should not be broken in ill-advised and premature attempts at its removal; in its fixed position it acts as an excellent guide to recesses and pockets that might otherwise have escaped notice.

3. All granulations should then be removed with the curette; during this stage of the operation one should stop whenever necessary to pack in small gauze swabs to soak up the blood which now keeps obscuring the field of operation. In this way sequestra gradually become free; where previously hidden by granulations they now become visible. And many a recess and cul-de-sac in the bone, in which other sequestra may be found lying, will become apparent. All these small cavities must now be converted into widely-opened grooves by the use either of the curette or chisel, according as the bone is soft or hard. Each time the cavity is swabbed out the walls should be carefully examined for the small greyish points of granulations that mark the openings of diverticula

and secondary cavities; these it is very necessary to open up, whether they contain sequestra or not.

RADIOGRAMS SHOWING THE RESULT OBTAINED BY SUB-PERIOSTEAL RESECTION OF ONE WALL (pp. 681-689.

FIG. 80.—Patient thirty-four years old; wounded by a piece of shell, 24th September 1914. Ineffective curetting performed several times, the last on 30th March 1916. The X-ray, 15th April 1916, shows the ineffectiveness of these operations. Radical operations with removal of numerous sequestra, 11th May 1916; healed, 15th July 1916.

All other sinuses than the ones already opened should then be explored with the probe in order to make certain that they do not originate from any point

of bone disease not yet exposed and dealt with in the main cavity or its already discovered recesses. The sequestra should next be all removed, even if it

FIGS. 81 and 82.—Patient aged thirty-five years; wounded by a piece of shell, 5th October 1914; sequestra present—enclosed in a cavity. Operation, 31st January 1916. X-rayed, 10th March 1916, showing the removal of the outer half of the circumference of the femur. September 1916 there still remained a superficial sinus.

be necessary to follow them far up and down the shaft. All granulations and foci of rarefying osteitis should be dealt with by vigorous curetting. In the case of an epiphysis, an excavation adequately per-

formed will sometimes leave nothing but the outside shell of bone.

Sometimes the shaft, thus weakened and attenuated, fractures, in which case, after a completion of the

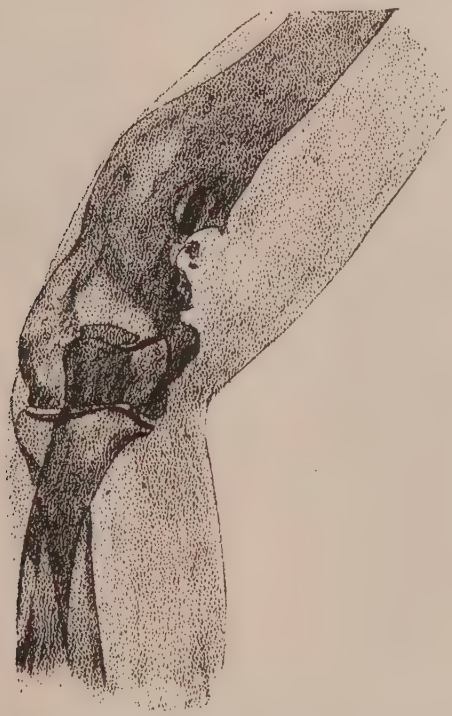
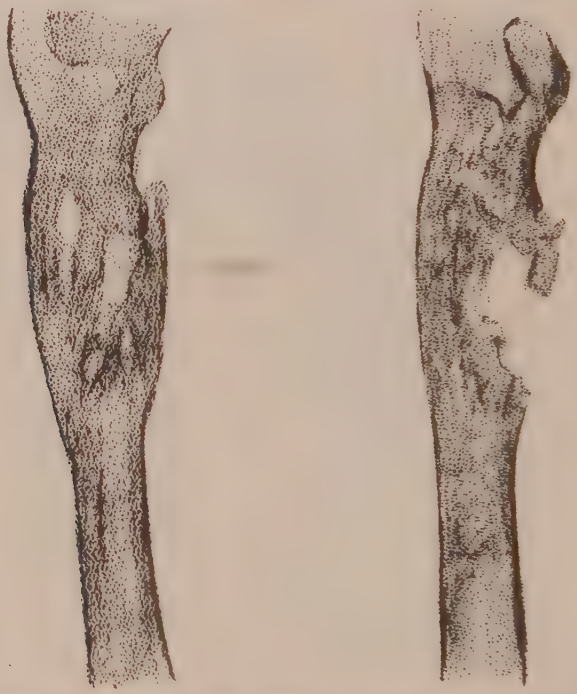


FIG. 83.—Patient aged twenty-five years; wounded by a piece of shell, 17th November 1914. There was present a cavity containing two large sequestra, despite two previous operations. X-rayed, 8th March 1916. Radical operation, 12th March 1916; healed, 1st April. On the 15th April he fell and fractured the bone, which, however, united well.

dressing, it will be necessary of course to immobilise as for an ordinary compound fracture. Such fractures usually unite well, just as do those accidental ones which sometimes occur in the course of an osteomyelitis.

The free incision of the soft parts that we have insisted on has as its object the complete removal of that wall of the bony cavity which is exposed by the operation. It is most necessary to carry out this stage of the



Figs. 84 and 85.—Patient aged twenty-one years; wounded by a rifle bullet, 18th January 1915. X-ray (9th March 1916) showed a large granulating cavity without sequestra. Fig. 85 shows the result after removal of one wall of the cavity, 15th March 1916. Still under treatment in September.

operation with the utmost care, so as to make quite certain that there is no bony arch or ledge left bridging or overhanging a granulating recess of the cavity. This done, the walls that remain and form the sides of the gutter thus produced should then be removed so as to convert this gutter into a groove as wide and

shallow as possible—to transform it, in fact, into an almost plane surface; in this way the transverse diameter of the bone that remains is much diminished, a column of bone sufficiently thick to maintain the continuity of the bony lever still, however, being

FIG. 86.—Patient aged twenty-five; wounded by a shrapnel bullet, 5th February 1915. There resulted a cavity containing a sequestrum despite two previous operations. X-rayed, 25th February 1916. Operation, 4th March 1916. Still under treatment in September, when I removed the anterior wall of the cavity. This I should have done at once at my first operation.

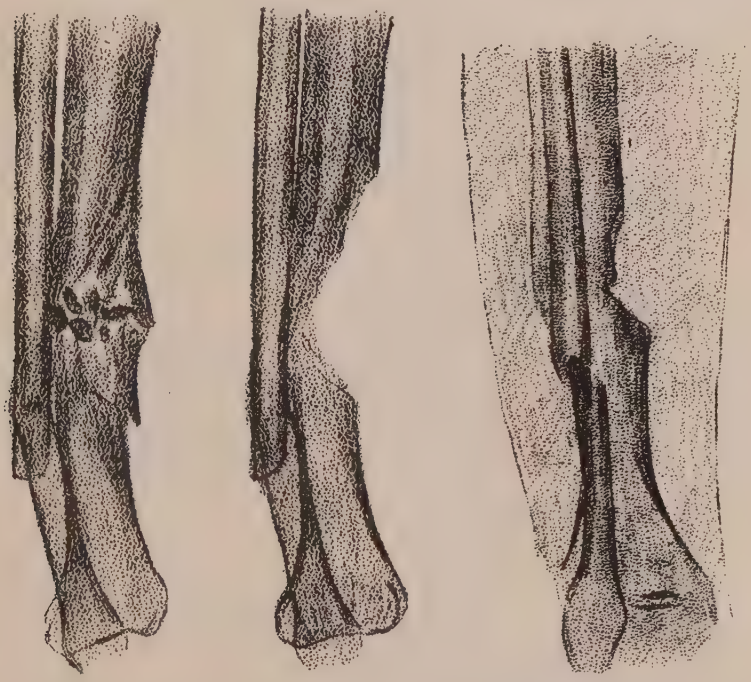
preserved. One need not be afraid of removing all the bone necessary, for it should be remembered that this hard bone left will before long be considerably reinforced by the progressive formation of new bone by the periosteum that was so carefully preserved during the first stage of the operation (figs. 81–93).

4. The object of these latter stages of the operation

FIGS. 87 and 88.—Patient aged thirty-nine; hit by a piece of shell, 13th October 1914. Several inadequate and unsuccessful operations. The cavity contained seven sequestra. X-rays taken respectively 3rd February and 27th May; almost cured in September.

is to bring about healing by such a utilisation of the soft parts as I must now explain.

It is essential, as I have already explained, that the soft parts should be allowed to sink into and occupy and—so to speak—carpet the floor of the groove that has resulted from the previous stages of the operation. This explains the necessity for the previous wide



FIGS. 89, 90, and 91.—Patient aged nineteen; wounded, 29th September 1915, by a rifle bullet; fragments removed 11th November 1915, and again 13th March 1916. X-rayed, 17th November 1915 and 15th April 1916, before and after radical operation. Cured, May 1916.

removal of the excess of new bone callus. The methods used to promote this desirable action of the soft parts are two :—

(*a*) *Packing.*—This consists in packing gauze into the cavity, whose walls soon become covered with granulations. These will later undergo ossification in

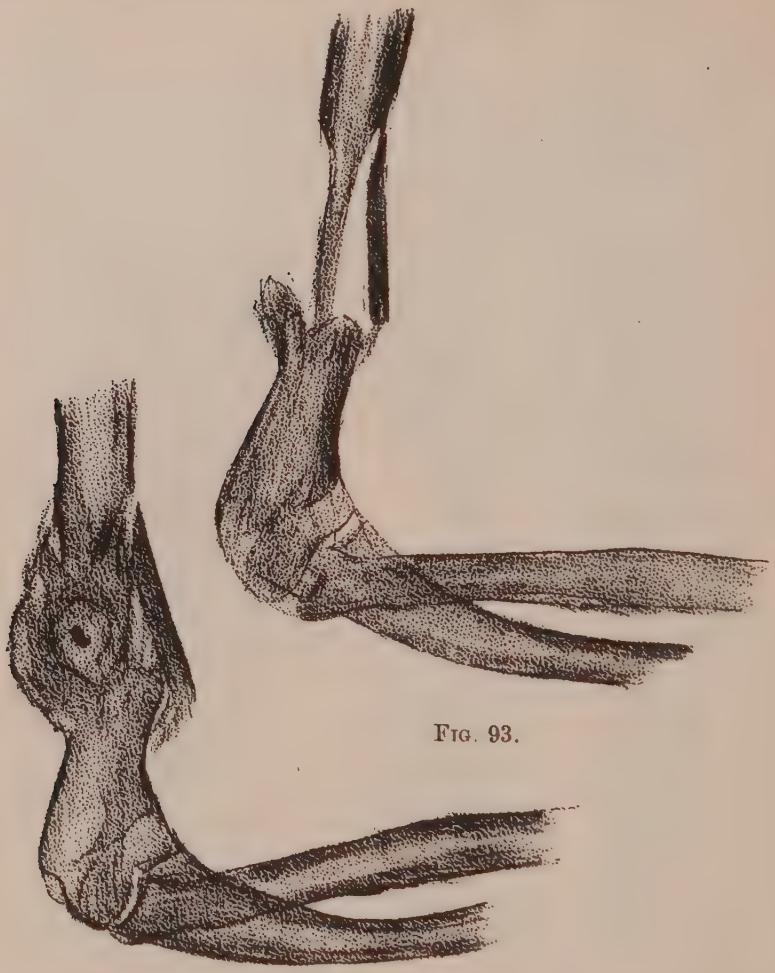


FIG. 93.

FIG. 92.

SHAFTS REMAINING SOLID AND FIRM DESPITE THE THINNESS OF THE BRIDGE OF BONE LEFT AFTER OPERATION. IN FIG. 92 THE NEW FORMATION OF SUB-PERIOSTEAL BONE IS STILL TRANSPARENT TO THE X-RAYS.

FIGS. 92 and 93.—Patient aged thirty-three; wounded by rifle bullet, 9th May 1915; received for treatment, 16th June. X-rayed, 27th July (after an operation on 19th June for suppurative osteitis and arthritis of the elbow joint). Radical operation including the removal of a sequestrum, 28th August, elbow joint stiff at a right angle—musculo-spiral paralysis.

two different ways: one, from their deep surface, by the activity of the osteoblastic elements in the walls of the cavity; the second, and more important, by the deposit of bone elements from the periosteum,

Fig. 94.—Patient aged twenty-six; wounded, 18th December 1914. X-ray, 12th January 1916. On the 15th January excavation of the bone and removal of two sequestra; healed, 23rd February.

which with the muscles and skin becomes gradually drawn inwards to the depths of the cavity by slowly-acting retraction of this very granulation tissue. In this way in the end a thin depressed scar adherent to the bone results.

This is a slow process, but often the best—often indeed the only one that is practicable.

If one has to excavate an epiphysis, especially one of the large epiphyses at the knee joint, in which it is impossible to remove one wall fully without opening the joint, this remains the only means at our disposal. This makes gradual ossification from the periphery towards the centre of the cavity necessary; hence healing is slow, and often delayed by troublesome recurrences of rarefying osteitis. Generally, but not always, healing takes five to six months, sometimes occurring only after further secondary operations.

It occurs most quickly—but even in this case within a minimum period of three to four months—after operations on tunnels and cavities in the middle of the shaft of an easily accessible bone like the tibia.

(*b*) The immediate collapse of the soft parts against the floor of the newly-formed groove often allows of a great shortening of the period required for healing, a procedure that is analogous to the operation of Estlander for chronic empyema.

After simple incision for empyema the lung, shrunken and bound down by the fibrous visceral pleura, can no longer expand and fill the chest cavity and come into contact with the parietal pleura; on the other hand, the bony framework of the chest, drawn in by the progressive fibrosis within, soon reaches the limits of its elasticity and of its capacity for collapse. However, after the removal of the underlying ribs the subcutaneous and muscular covering of the thoracic wall may be utilised to fill the cavity, the result being an obliteration of the latter, sometimes due to an immediate collapse of the parietal pleura against the lung surface, but more often to a

more gradual approximation of its two walls, the parietal pleura and chest wall being now no longer able to resist the cicatricial pull from within. A suppurating cavity with rigid walls has thus been converted into a cavity with at least one collapsible wall.

This is exactly what we have achieved in such a complete removal of the roof of the sequestral cavity as allows the soft parts to sink into and occupy the groove thus formed.

To assure the fulfilment of this condition it will often be necessary to free the skin extensively. Especially around the opening of sinuses is it adherent and puckered up into funnel-shaped depressions which, adhering to the bone, would effectively prevent collapse of the muscles into the grooves. By horizontal undercutting till normal subcutaneous tissue is reached we can easily loosen and free the skin over a sufficient area and to a sufficient extent to allow the musculo-periosteal layer to fall inwards and occupy the excavated bony surface. When the muscles have become almost completely fibrous and the joint they normally act on is ankylosed, transverse division of them across the direction of the wound will often assist considerably in the attainment of this aim.

If this be done, direct packing of the cavity can be replaced by packing gauze between the skin and muscle so as to force the muscles into the bone groove, and at the same time counteract the constantly present tendency of the skin edges to invert.

In cases where all the recesses seem to have been well opened up and the remaining bone surfaces appear everywhere firm and compact, with no soft areas of rarefaction visible to the naked eye, we may

even attempt immediate suture, either incomplete or complete, of the skin; a large drainage tube should be inserted either into the bony cavity or, where the muscles occupy and fill up the cavity, between them and the skin. Union in these cases, however, is always rather slow, because in unhealed war wounds operative interference always excites a revival of microbic activity, which is often astonishingly severe, although the original wound may have been of long standing; there reappear the green pus, even the superficial sloughing of the edges of the incision, the abundant and profuse and fetid suppuration of the original infected wound; even necrosis of a thin layer of the excavated bony surfaces is not rare. Careful supervision is necessary then in these cases. The chief danger arises from the formation of a hæmatoma, that forms so fine a bed for infection. All precautions should therefore be taken to prevent this happening by firm bandaging of the limb. If union of the edges of the wound results, the drain should be removed at the end of a week, and in exceptional cases final healing will rapidly occur.

Usually, however, a cavity and sinus persist for a variable time, but these gradually decrease in size and finally heal. Often either the sinus remains constantly open and discharging, or else it closes and reopens after a longer or shorter period of temporary healing; and it heals finally either after the spontaneous elimination of a small piece of necrosed bone, or else after the performance of one or two slight secondary operations, which may now be quite correctly described as "scraping" or "curetting"; not rarely a small sequestrum hidden away in a recess has been overlooked; or in scraping out the cavity the curette

has spared some small fragments destined to undergo subsequent necrosis; or again, secondary necrosis may occur at certain projecting points of the new bone surface left by the operation. Such occurrences are, however, not sufficiently frequent or serious to contra-indicate attempts to suture the wound; much time may thereby be gained at the expense of a possible slight secondary operation. Often the attempt at primary, or at least early, union fails, a profuse blood-stained discharge appears, the skin becomes red and inflamed. It then becomes necessary to remove the stitches and resort to packing with gauze.

These general rules must not be followed too rigidly; of course they will require modification according to the local necessities of each case, especially those anatomical relations that should regulate most definitely the means of approach to the affected bone, and to a less extent also modify the details of the operation.

(*a*) **The shaft of a long bone with an extensive subcutaneous surface or border**—*e.g.* the tibia (subcutaneous inner surface), the ulna (subcutaneous posterior border), and the clavicle (subcutaneous upper surface).

These bones are very easily reached over their whole length by an incision running parallel to their subcutaneous surface and half-way between its borders; the periosteum and subcutaneous coverings of this surface should then be completely elevated from the bone by the use of the rugine; the cavity should be opened and converted into a gutter, the walls of which are then to be cut away so as to give them as gentle a slope as possible. Any operation performed differently through a sinus that does not lie in the line of this incision of choice is on that account alone to be

condemned. The method of approach for excavation of the two epiphyses of such a bone is identical with this for the shaft.

In cases where the cavity lies in the middle of the shaft, after removal of the bridge of bone—often of great width in the tibia—and levelling of the edges of the cavity have been performed, the two flaps, consisting of periosteum, subcutaneous tissues, and skin, usually sink in quite readily and occupy the floor of the groove thus formed : if they lie in good contact with this, primary union may be attempted, the limb being dressed and firmly bandaged.

(*b*) **The shaft of a bone everywhere surrounded by a thick mass of muscle, as in the femur and humerus.**—In exposing these bones it is necessary to remember their relations to the vessels and nerves. Sinuses of the femur often open internally or (in the lower third of the bone) posteriorly. Now in these directions lies the artery, which prevents freedom of incision and operative manipulation. The only good position in which a free incision can be made is the outer aspect of the thigh, where, if necessary, it can be extended from the great trochanter to the external condyle. It is usually most convenient to expose and resect the antero-external part of the enlarged bone ; into the cavity thus formed and lined with periosteum the quadriceps extensor muscle sinks ; gauze packing may be used to keep this in position. If the knee is ankylosed, however, this may be more easily effected by simply dividing this useless muscle transversely.

The different parts of the humerus requires separate consideration.

In the upper portion, provided the shoulder joint is

not ankylosed, great care must be taken not to injure the circumflex nerve supplying the deltoid. One should therefore approach this part of the bone from the front through the groove between the deltoid and the pectoralis major, or else a little further out through the anterior fibres of the deltoid.

This incision, which lies just external to the biceps, can at need be extended downwards along the anterior surface of the bone through the fibres of the brachialis anticus. It is the only suitable incision for reaching the middle third of the shaft, the musculo-spiral nerve here winding round the other surfaces of the bone. Use may be made, however, of the existence of posterior sinuses in the upper third of the bone, behind the posterior border of the tendon of the deltoid. By such an approach either the anterior or the external wall of a cavity can be removed, the deltoid —which may be divided in cases of ankylosis of the shoulder joint—coming to occupy the bony groove thus produced.

Good access to the lower half of the shaft may be obtained by either one or, if need be, two vertical incisions corresponding to the internal and external supracondylar ridges; such an external incision, however, should not reach higher than the lower third of the shaft, so as to avoid crossing the track of the musculo-spiral nerve.

If there is a posterior sinus from the lower third of the bone, a vertical incision deepened through the triceps serves as an excellent means of approach; a similar approach through the triceps to the upper third of the bone between circumflex and musculo-spiral nerves is possible, but is rendered inconvenient by the thickness of the muscle at this point. In

places like this, where one has to operate through a thick muscular mass, either packing between skin and muscles or else closing the wound with drainage will be found necessary.

The radius should be reached on its outer side. The incision should be deepened through an intermuscular plane, the muscles here being very easily separated and retracted. Its lower end should be exposed either from the back or from the outer edge of the forearm.

The surgical surface of the fibula is its outer surface, which should be reached by passing between the peronei in front and the muscles of the calf, *i.e.* along the external intermuscular septum; it should not be forgotten that the external popliteal nerve winds round the neck of this bone.

(*c*) **Epiphyses and short bones.**—I have already dealt at sufficient length with the diffuse osteitis of such cancellous bone; I have pointed out the impossibility of completely removing one wall of the cavity, the necessity for methodical packing of the cavity, and the length of time necessary for cure. I will say no more, then, about the large epiphyses at the knee joint. Some details of the treatment of the disease when it occurs in the bones of the foot are, however, necessary.

In the foot all operations on the posterior bones of the tarsus and the cuboid should be undertaken from the outer side, whilst the scaphoid and cuneiform bones should be approached from the dorsum or inner border of the foot. The incisions should be in the long axis of the foot, so as to avoid damaging the tendons. As a general rule, one should avoid using the plantar surface.

Cases of caries of the os calcis are most obstinate. Removal of diseased bone leaves a cavity that it is most difficult to heal, and at times one is forced to resect *en masse* a considerable part of the bone. Through and through drainage by a counter-incision behind the internal malleolus is easily achieved.

After excavation involving the anterior tarsal bones

Fig. 95.—Patient aged twenty-four; wounded by a piece of shell, 22nd June 1915; succession of abscesses and persistence of sinuses. X-rayed, 2nd March 1916. Rarefying osteitis and sequestra. Foot fixed in equinus and slight varus. Radical operation, 27th March. Discharged with a small sinus, 28th July.

and the bases of the metatarsals—whether such excavation has been performed early or late—the foot should be immobilised at a right angle, and this position maintained in plaster over a long period. This is necessary if one wishes to avoid that most troublesome complication—fixed equinus of the anterior part of the foot, the result of permanent flexion at the disorganised mid-tarsal joint. This flexion is produced

by progressive contraction due to inflammation and subsequent fibrosis of the muscles and ligaments of the sole of the foot, and the resultant shape of the foot is comparable—only with more dropping of the front part of the foot and less advance of the heel—to the pes cavus of infantile paralysis. Sometimes the destruction of bone is so extensive and the contraction of the plantar ligaments and tendons so excessive, that the deformity appears even after a long course of immobilisation, that has, however, proved insufficient for the production of ankylosis in a good position. Whether this flexion has been inevitable or the result of careless treatment, it should be corrected in either case by transverse tarsectomy—linear unless there be a varus element in the deformity, when it should be cuneiform : this operation is most easily undertaken through a longitudinal incision along the outer border of the foot, just as in tarsectomy for club-foot.

(*d*) **Flat bones.**—Thick-walled cavities in the iliac crest should be exposed and dealt with through an incision parallel to the crest itself. Similarly, the outer surface of the ilcum should be approached by splitting the gluteus maximus in the direction of its fibres.

In the scapula, the two favourite positions for enclosed sequestra are the axillary border and the spine ; I have met with several cavities in the root of the acromion.

(*e*) **Ankylosis of joints with sinuses present leading to the epiphyses.**—In such cases the sinuses lead down directly to the focus of diseased bone, and can, after being incised, generally be utilised for the passage of the curette ; in cancellous bone the chisel is but rarely of

use. If a more extensive and radical operation is indicated, the classical incision for the approach to the joint for resection should be used.

If the joint be ankylosed in bad position, this should be corrected by an orthopædic resection—the technical details of this method will vary with the amount and nature of the desired correction ; it will be understood that in such cases one must not promise any great return of movement.

I have described the operation that should be performed immediately in the case of sinuses of osteomyelitic origin that have been allowed to become chronic, the patients, for lack of a proper decision to perform a radical operation, having been allowed to waste a year or more passing from one hospital to another. Much more rapid results can be obtained by very much less extensive and difficult operations by a surgeon, who by reason of his special knowledge and experience knows exactly at what moment to intervene alike in the case of the primary as of any secondary operation that may become necessary.

Figs. 96–100 are the radiograms of patients who have remained under my charge from the early days of their wound, when they were first admitted with severe infection into hospitals. Those of the fractured femur need no commentary, except that a study of the dates in these cases shows that very late final healing must be expected even in the hands of surgeons competent to practise the surgery of bone.

Figs. 98–100 are intended to show that in compound fractures into the elbow joint I restrict myself to simple removal of fragments and sequestra, not a real formal resection. I do not wish to imply, however, that better results might not have resulted had early primary

resection been performed before the onset of signs of infection; but if the shattering of the bone has not been excessive, anklyosis at a right angle (fig. 100) gives a better result than that furnished in most cases

Fig. 96.

that have been subjected to full secondary resection. A good example of this is shown in figs. 98 and 99, where the extent of the damage (to the lower end of the humerus) was very great.

I shall finish by giving some idea of the way in which cases are treated in my hospital practice, cases that

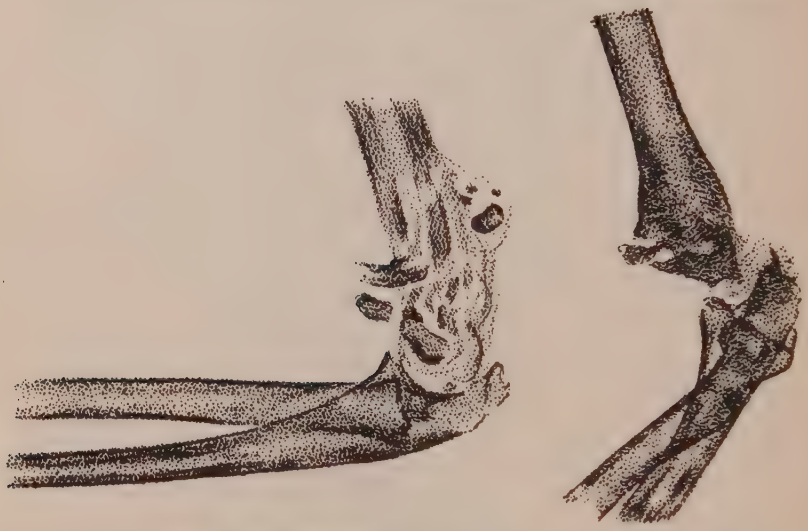
arrive some two to five days after being wounded, and hence at a time when it is too late to attempt to prevent infection. If there be no suppuration, of course no operation is necessary, and the fracture is immobilised

FIG. 97.

FIGS. 96 and 97.—Patient aged twenty-eight; wounded by a piece of shell, 11th May 1915. Incision and removal of fragments causing severe inflammation, 15th May. Bone immobilised in Delbet's apparatus. Several small sequestra spontaneously emerged. Radical operation with removal of eight sequestra, 3rd September 1915, then again 29th November 1915 and 5th January 1916. X-rays 3rd November 1915 and 16th February 1916 respectively. Healed by the end of July 1916.

and treated just like any simple fracture. In these, of course, secondary infection may occur; but when it does, it is but moderate. It occurs especially, though not inevitably, when foreign bodies remain in

or near the bone, and especially often also in wounds due to bullets whose covering has been torn or that have broken up into fragments. But even in these conditions aseptic enclosure of the fragments is possible. In such cases, then, it is not necessary to intervene at



FIGS. 98 and 99.—Patient thirty-one years old; wounded by a piece of shell 28th September 1915; shattering of the lower end of the humerus, with a very large wound behind and on the outer side; suppurative arthritis with gas formation, incision, free drainage, removal of all free and adherent fragments. Radiograph, 26th December. Healed with the formation of an articular pseud-arthrosis of the elbow, 10th February 1916. When seen again (fig. 99), 8th September, the elbow joint was flail as regards lateral movement and extension. Flexion could be actively carried out, and reached the right angle with a fair amount of stability. The musculo-spiral nerve, which had been temporarily paralysed, had recovered; the ulnar nerve remained paralysed.

once, but one should be prepared for the probable onset of inflammatory signs. Fortunately the necessity for the removal of such fragments arises most often in cases where this is most easy to accomplish, but one would never dream of attempting to remove all the

fine metallic powder revealed by radiography. The information furnished by radiography, however, is not always absolutely accurate, for sometimes a piece of lead will strike a piece of bone and discolour it, so that it becomes opaque to the X-rays and throws a shadow indistinguishable from that of a metallic foreign body.

These fractures should be carefully watched; the

FIG. 100.—Patient aged twenty-three; wounded by a bullet, 25th September 1915; severe inflammatory complications. X-ray, 25th March 1916. Radical operation with removal of a sequestrum, 3rd April 1916; healed, 29th May 1916, with ankylosis of the elbow-joint and musculo-spiral paralysis.

temperature carefully taken; the absorption of aseptic blood effused at the time of injury is always considerable; there is usually some œdema and inflammation of the soft parts. The callus is often bulky and tender; some infection generally exists at the point of entrance of the projectile. The least suppuration at this entrance wound should make us fear its exten-

sion to the bone itself, an extension which may take place slowly and lead to osteitis even after consolidation of the fracture is already far advanced, but no risk should be run by a premature and harmful opening up of the seat of fracture during the period of early aseptic infiltration and inflammation.

A similar course of action is adopted if, in the absence of foreign bodies, the wound is large and the suppuration moderate in amount. Immediate treatment is regulated by the severity of the inflammatory signs in the soft parts; when incision and drainage of these is necessary, all loose fragments of bone should be removed as well as adherent fragments, for these latter are practically certain to necrose. But this operation, which certainly limits the spread of the traumatic osteomyelitis, does not entirely do away with the septic process, and it is the rule, almost without exception, that the ends of the fractured bone undergo necrosis and form secondary sequestra even in cases where one has succeeded in removing all the primary ones. Hence sinuses are practically inevitable, and later operation a necessity, but this should not be performed too soon; the abscesses that often form round the infected seat of the fracture should, in the meantime, be opened without interfering with the bone condition at all. It is necessary to allow time for sequestration to occur, for until it is complete it is impossible to determine the limits of the necrosed bone; and during this period too the bony fragments act as a support to the periosteal sheath which, by producing new bone, is going to re-establish the continuity of the bone. In young patients it is often astonishing what degree of regeneration can obtain in fractures so comminuted or with

such loss of substance as to make one fear the production of a false joint.

For these reasons then, although successive sequestra which find their way into the sinus track should be removed with forceps, the radical operation we have described should not be attempted too soon; nor too late either, in order that the newly formed bone enclosing the sequestra may not itself become the seat of a progressive rarefying process. The time necessary for the completion of sequestration varies directly and almost definitely with the size of the bone; in the femur it takes two or three months, in the radius or ulna five or six weeks. At the end of these respective periods, and after careful radiographic study, the operation of removal of all sequestra and obliteration of the cavity should be practised. Healing after this is almost always slow; in a large bone it often takes five or six months. Hence a fractured femur often takes altogether some eight or ten months from the date of reception of the wound before final healing is obtained, and this period will be longer where a second operation or, as in some cases, several at six-weekly or two-monthly intervals become necessary.

Again, the re-opening of abscesses and sinuses sometimes occurs quite a long time after apparently final healing. And if ten years hence some one were to show me some of these cases, especially of the lower third of the femur, still continuously or intermittently suppurating in spite of successive and well-carried-out operations, I should answer that my former knowledge and experience of the spontaneous osteomyelitis of childhood had led me to expect such things. It has also led me to expect cases—exceptional ones certainly

—in which, repeated radical operations having failed to arrest progressive invasion of the bone by disease, late amputation will be necessary. Already I have been forced to amputate three thighs and disarticulate one hip joint after vain attempts to cure such a suppuration accompanied by chronic septicæmia. All four cases are now healed and cured.

CHAPTER IV

THE AFTER-EFFECTS OF WOUNDS IN JOINTS, MUSCLES, AND TENDONS

EVEN after firm union and final healing many cases of gunshot fractures—even where there has been no direct original involvement of the joint—end with ankylosis, or with considerable limitation of the normal range of movement of joints due to lesions either of the articular tissues themselves or else of the muscles that are normally concerned in their movement.

Too often such cases are sent in large numbers to a centre of physiotherapy, where too often also, in the absence of careful examination and accurate diagnosis of the cause or nature of their disability, they are submitted to a full course of treatment—massage, the various forms of electricity, baths and douches, passive and instrumental movements. All these methods of treatment, of very considerable benefit in certain cases, are in others not only useless but often harmful.

The differentiation of these cases is often a matter of difficulty, I know, because the various factors that have to be taken into consideration are numerous and often contradictory ; and if one attempts the classification of the cases met with on some pathological or etiological basis, it will soon be found that the over-

lapping of categories is so frequent and so confusing as to render impracticable the best thought-out and most comprehensive scheme.

1. The Pathological Varieties of Ankylosis, Stiffness, and Deformity of Joints

Ankylosis means the limitation in any way of the normal range of movement of a joint,[1] and it is necessary first of all to remember that ankylosis comes into being only when the pathological process that causes it has ceased to exist. Because of ignorance or forgetfulness of this fact many serious errors of treatment have been committed. As long as the pathological condition causing the ankylosis is still in existence, it and not the ankylosis should be the object of treatment.

Ankylosis, thus defined, includes, then, all degrees of interference with the movement of a joint, from the slightest diminution of one movement to complete absence of all movement; hence, clinically, ankylosis is either complete or incomplete.

If, however, we wish to classify cases of ankylosis on an anatomical basis, we distinguish two varieties according to whether the causative lesion is intra-articular or extra-articular.

1. *Intra-articular ankylosis.*—This is the result of an arthritis—plastic, serous, or suppurative—which has produced in the joint the following pathological conditions:—

[1] In England "ankylosis" is generally used in a more limited sense, including only true bony ankylosis and firm fibrous ankylosis, so that the classes here described as due to extra-articular lesions would be included under restriction of movement of a joint rather than under ankylosis.—(Ed.)

(*a*) The articular cartilage of the ends of the bone becomes eroded and gradually disappears, thus leaving bare the surfaces of the bones, so that they subsequently undergo bony or firm fibrous union.

Bony ankylosis, the usual result in adults of a suppurative arthritis, is, of course, necessarily a complete ankylosis.

Interosseous fibrous ankylosis, much less common in such cases, is almost always very firm and practically complete.

(*b*) Next in a theoretical classification of these intra-articular lesions would come the obliteration by plastic inflammation of the synovial pouches and recesses, and the contracture of capsule and ligaments; these are usually associated with some disintegration of the articular cartilage and deformity of the articular surface of the bones; in these cases incomplete ankylosis is the rule; sometimes, however, the loss of movement is so great that it is practically complete.

The original lesion in such cases is always an arthritis; but where the articular surfaces remain normal or almost so, with only slight erosion of the cartilage as the result of a dry arthritis, the synovial and ligamentous changes should be clinically regarded as constituting an ankylosis rather of peri-articular origin.

2. *Extra-articular lesions.* — These occur either in the bone or in the peri-articular soft parts.

(*a*) When the *articular end of a bone* is deformed, the result either of excessive callus formation or of an excessive inflammatory production of sub-periosteal deposit, a mechanical disability of the joint results.

The purest example of this resulting from excess of callus occurs in supra-condylar fractures of the

humerus, when the badly reduced lower end of the shaft limits flexion of the elbow joint.

The classical example of joint disability from inflammatory hyperostosis is the incomplete ankylosis of the knee following osteomyelitis of the lower end of the femur. Instead of gliding round the articular surface of the femur like the strap of a helmet round the chin, the tibia finds its progress in flexion of the knee arrested where the femoral condyles are enlarged.

The disability is increased when in addition to this bony obstruction there exists also more or less fibrosis and contracture of the synovial membrane and ligaments, the joint having been the seat of a chronic inflammation by continuity from the diseased bone. In such a case we get an association of both peri- and intra-articular lesions, but the latter are of but secondary importance; and the all-important fact to remember in considering the treatment is that the extra-articular cause of the trouble is bony and unyielding, causing a mechanical arrest of movement that no mere manipulation or forcible correction will succeed in overcoming.

(*b*) The *lesions of the peri-articular soft parts* may involve any of the neighbouring tissues, may consist in thickening and fibrosis of the intermuscular planes and septa, in the obliteration of tendon sheaths and their adherence to contracted tendons, in atrophy and fibrosis of the muscles.

At the same time, as we have already described as occurring in the joint lesions of chronic osteomyelitis, the inflammation extends inwards to involve to a variable degree the capsule and synovial lining of the joint. In exceptional cases parts of these peri-articular tissues actually undergo ossification, and

form bridges of bone which constitute one form of extra-articular bony ankylosis; in such a condition all methods of treatment short of operation are hopeless.

Here again, then, we find an association of lesions within and without the joint, but the original lesion is an extra-articular sclerosis, which in itself is amenable to cure, or at least to improvement, without the necessity for a bone operation.

It will be understood, then, that up to a certain point, though always with the reservations we have made, cases may be classified, upon an anatomical basis, into stiff joints and ankylosed joints proper.

The cases of mere stiffness—almost always extra-articular in its origin—are associated especially with sclerosis of the soft parts.

The cases of ankylosis—properly so called—result chiefly from alterations in the articular ends of the bones.

3. *Lesions of the muscles and tendons.*—We have been dealing so far with articular lesions, lesions due to suppurative or plastic arthritis and peri-arthritis, involving the structures of the joint itself or the parts surrounding and enclosing it. We have still, however, to consider abnormal limitation of the range of movement of a joint due to a pathological condition situated at a distance from the joint, resulting from some interference with the equilibrium normally maintained between the groups of muscles acting on the joint.

Such lesions are of two different varieties:—The paralysis of certain muscles with overaction of their antagonists. The retraction or contracture of certain muscles that results in more or less permanent approximation of their points of origin and insertion.

Every one, for example, is familiar with the drop-wrist of musculo-spiral paralysis, the foot-drop of external popliteal paralysis. Such cases, at least when uncomplicated, belonging, as they do, to a very special department of surgery, should be studied in connection with the phenomena of traumatic lesions of the peripheral nerves. But in the surgery of war these cases are often complicated by a rapidly developing secondary stiffness of joints due to sclerosis of muscles, joints, and ligaments, to the importance of which I wish to draw special attention.

From my experience of severe suppuration and diffuse inflammation of the limbs in civil surgery, I cannot say that I can detect much difference between the after-effects in such cases and those in similar lesions occurring during the war and due to infected projectiles. The muscular atrophy and the loss of movement due to adhesions and sloughing of tendons of our war experience seem to me to be identical with what we saw in civil practice. Before the war we were quite familiar, for instance, with those common results of extensive inflammation in the upper limbs, viz. fingers blue, cold, and stiff with thin transparent skin, wrists frequently fixed in semiflexion and semi-pronation. When one got the chance to dissect such a limb the muscles of the forearm were found to be fibrous and greyish-red, their normal colour almost entirely absent, the intermuscular planes obliterated and fibrous and replaced by masses of tough fibrous tissue strangling the nerves and blood-vessels; the tendon sheaths adherent to their tendons; articular ligaments hard and contracted; and where the immobilisation, often in a bad position, has been of long duration, considerable erosion of the articular cartilages.

What does seem to me peculiar, however, in the wounds of this war is that condition of atrophy combined with sclerosis and contracture at times induced in certain muscles by even a slight injury, for example, by simple penetration by a bullet. Of course such progressive sclerosing myositis is more likely to result where suppuration has occurred, but I have seen it several times, especially in the calf muscles, follow mere penetration by a bullet, the tract healing in a few days without suppuration beneath the small scabs that mark the points of entrance and exit. This condition seems akin to the progressive sclerosis that follows obstetrical injury to the sterno-mastoid muscle and results in the development of torticollis, the muscle in time becoming completely fibrous throughout its whole length and thickness.

The nature of this progressive sclerosis in torticollis, unknown in connection with subcutaneous rupture or aseptic wounds of any other muscle, has been the subject of much controversy; I know that the chief part in its production has been attributed to congenital syphilis, the influence of the obstetrical rupture of muscle fibres being either relegated to a position of but secondary importance or else denied altogether. I am willing to grant that the pathogeny of this condition is still as uncertain as that of this certainly traumatic muscular contraction to which we have just referred, a contraction accompanied by an induration and atrophy of the whole muscle mass altogether out of proportion to the extent and severity of the original wound. I may add also that such contraction does not seem to be associated with any lesion of the nerve-trunks of the limb, which, clinically, always appear quite intact.

Possibly, as has also been maintained as regards congenital torticollis, this may be a form of that curious ischæmic contracture of muscle which we see from time to time following simple fractures, especially in young people, and almost exclusively in simple fractures about the elbow joint or of the bones of the forearm.

The same thing occurs too in cases of mere contusion or rupture of muscle associated with the formation of a large hæmatoma and of too prolonged constriction of the limb by a tourniquet; hence it would seem that the muscular ischæmia is the primary cause of the myositic degeneration. This would explain the rôle played in its production by constriction or compression by too tight splinting; also the occurrence of this lesion in the absence of any such external cause of pressure in cases where trauma has led to great swelling, with effusion of blood and widespread œdema, and hence to compression of blood-vessels, and to a certain extent also of nerves.

This is not the place to discuss the exact nature and cause of this ischæmic contracture, to decide whether the circulatory condition is primary or secondary, whether this acts exclusively or directly on muscle fibre, whether the nerves, at first apparently unaffected by it, undergo a secondary compression. My object has only been to compare the phenomena of this ischæmic contracture with those of the fibrous degeneration of muscle that we see so frequently in cases of gunshot wounds, in which there may or may not be an accompanying fracture, and in which suppuration is severe, or slight, or absent.

Joints that have assumed fixed positions on account of interference with the equilibrium of the various

groups of muscles acting on them do not as a general rule undergo secondary changes, at any rate for a long time; such fixed positions are easily corrected by tenotomy. This may be seen every day in the various forms of paralytic club-foot, in which, when there does occur an obstacle to full correction, this is not of an inflammatory origin, but consists merely of an overgrowth or deformity of bone due to abnormal transmission of pressure through the foot.

In the case of war injuries, however, joints originally perfectly sound and free, often seem to become fixed in bad position with extraordinary rapidity. It is practically certain that they are really the seat of a subacute inflammation. Even in cases without fracture, or in which suppuration is absent, one is often struck with the relative intensity of the immediate swelling, the effusion of blood, the firm, and at first solid, œdema. All these appear at their maximum in cases of compound fractures; for example, with fracture of the femur or of the humerus the œdema is very considerable in the leg and foot and in the arm and hand respectively.

We do not know to what distance up and down from the actual wound this œdema may be directly involved in the infective process, and liable to end not in simple absorption but in fibrosis. Sometimes it certainly is infected. I have been very much struck with a phenomenon which is quite unique in my experience, and I think most interesting in this connection. In a patient with a very severe compound fracture of the femur received some months previously I forcibly corrected under a general anæsthetic an equinus position of the foot, and in so doing brought about an acute suppurative inflammation of the ankle joint.

This unfortunate case of an infection, latent but obviously severe, and awaiting only such an opportunity to become active, explains why, in a considerable number of cases of deformity of joints due to muscular sclerosis and retraction, a secondary stiffness of arthritic or peri-arthritic origin so often occurs. To an already existing abnormal position of the joint has been added a subacute or chronic inflammatory process.

2. The Treatment of Ankylosis and Stiffness of Joints

A. *Preventive Treatment*

In every case of inflammation of a joint, whether the result of its direct involvement in a wound or whether indirectly produced by fracture of a neighbouring epiphysis, we must anticipate from the outset the occurrence of its almost certain ankylosis, partial or complete. Our duty then is plain—to fix the joint so that if or when ankylosis takes place it will leave the limb in the position which is most favourable to, and most compatible with, its greatest subsequent utility.

The first indication, then, in the treatment of articular inflammation is the most rigorous immobilisation of the joint in this position of election.

No one would dream of contesting this rule in so far as it refers to suppurating joints, which should be fixed as early as possible in some suitable apparatus compatible with careful observation of the inflamed tissues and with the positions of the wounds or surgical incisions. But before the application of this, for which a general anæsthetic is very often necessary,

we should strive by means suitable to each particular case (continuous extension, adjustable or flexible splints, successive starched bandages) not only to approach gradually the attainment of the ideal position, but also to prevent any such further development of mal-position as only too surely would happen if this precaution were neglected.

The respective mal-positions spontaneously and inevitably developed by each of the large joints of the limbs when inflamed are as follows :—

At the hip joint, flexion, adduction, and internal rotation.

At the knee joint, flexion.

In the foot, the position of equinus.

At the elbow, pronation and extension of 135°.

At the wrist, semi-flexion.

Now, not only are these respective positions disadvantageous in the actual treatment of the existing inflammation of the joint, but they will all, without exception, on the completion of ankylosis constitute grave functional disabilities.

The positions which are most certainly both ideal during the acute phase and later, after ankylosis, the most favourable from the point of view of utility of the limb, are :—

At the hip joint, the vertical position, *i.e.* neither flexed nor hyperextended, neither adducted nor abducted.

At the knee, full extension.

At the ankle and tarsal joints, the foot at right angles to the leg, or even 12° to 18° less than the right angle, the foot neither in varus or valgus.

At the shoulder, the arm by the side of the trunk or in slight abduction and flexion.

At the elbow, a right angle, the forearm midway between pronation and supination.

At the wrist, forearm and hand in one straight line; for an inter-phalangeal or metacarpo-phalangeal joint, full extension.[1]

I know quite well that there has been an attempt to systematise the extension of the wrist joint to 25° to 30°, the extension of the elbow to 135°, with the forearm in full pronation, because these positions are alleged to give better functional results in certain manual occupations. For almost all the ordinary acts of life, however—*e.g.* in eating—these latter positions are unsuitable, and hence to be condemned, except perhaps in a few cases with special occupational requirements.

Complete ankylosis of the tarsal and ankle joints is quite compatible with very fair powers of walking if the foot has been maintained at a right angle to the leg, with good powers of walking if this angle is slightly acute. In cases of simple stiffness of the

[1] There is room for a slight difference of opinion as to the ideal positions of joints. At English orthopædic centres the positions adopted are usually the following:—

At the hip, extension and slight abduction, with the foot turned a little out.

At the knee, full extension.

At the ankle, right-angled position, with the foot neither in varus nor in valgus.

At the shoulder, abduction to about 60°.

At the elbow, usually flexion to 100°, with the forearm in the position of supination. Some, however, prefer a right angle or less, and some prefer full supination.

If ankylosis of the elbow is expected, the angle at which it is set should depend upon the patient's work.

If loss of pronation and supination is expected, the position should be semi-pronation; if it is expected that these movements will return, the position should be that of full supination.

At the wrist, extension to 45° beyond the straight line.

At the metacarpo-phalangeal and the inter-phalangeal joints, very slight flexion.—(Ed.)

ankle joint with retention of a certain range of movement flexion should at least reach, better pass, the right angle in order to allow of fair walking. Ankylosis or stiffness at an obtuse angle, *i.e.* in equinus, constitutes a very grave disability. The first mechanical result of this is an elongation of the limb; this certainly may not be a disadvantage in a previously or simultaneously shortened limb, especially if the patient is fitted with a surgical boot in which the heel is raised more than the fore part, so that he walks in equinus. But if, on the other hand, the limb is of normal length, then the patient, walking on the heads of the metatarsal bones with the heel in the air, has to flex the knee to correct the lengthening of the limb. In slighter cases of this deformity the patient does put the sole flat to the ground in walking, but this necessitates an obliquity upwards and backwards of the leg, which again is corrected by an upward and forward obliquity of the femur; this puts abnormal tension on the knee joint, which in time becomes a real "genu recurvatum."

(*b*) When the joint does not suppurate, the inflammation having been but serous or plastic in its nature, an inflammation by contiguity from a fractured epiphysis, many surgeons—although I believe their number has decreased since the war—are opposed to immobilisation. In my opinion they are wrong; absolute immobilisation in plaster seems to me still the best means of resolving the inflammation, of lessening the chances of ankylosis, or at least of limiting its extent. Ankylosis in these cases results not from the immobilisation but from the inflammation.

(*c*) This does not mean, however, that the immobili-

sation of a healthy joint is quite a harmless procedure; its ill-effect varies, however, with the age of the patient, with the joint immobilised, and with the nature of the lesion that is being treated.

To consider the effect of age first: in a child immobilisation of a normal joint hardly ever results in any stiffness; a knee joint that has been immobilised in plaster for months in a patient with hip disease soon regains almost of itself its original range of movement. This is not so, however, in older patients, especially if the joint has been fixed in a bad position; the stiffness that results in such a case is usually in direct proportion to the age of the patient.

The tendency to stiffness is specially noticeable in small joints where the articular surfaces fit closely; the ready stiffening of the joints of the fingers is a good example of this. It is not at all uncommon for old people to develop obstinate, troublesome, and disabling stiffness of shoulder and fingers in cases where for some more or less limited lesion the whole limb has been fixed perhaps only in a sling, a lesion that could with a little care very often have been as well, and much more wisely, treated by allowing complete freedom of movement to these joints.

Consequently in the treatment of gunshot fractures we should aim at immobilising absolutely the fracture itself, and at the same time reducing to a minimum all restriction to the movement of neighbouring parts. Extensive plasters—either bridged by metal bars or with cut-out windows—which immobilise the whole limb are much the best form of splint for wounded men during their evacuation to the base, but once arrived in a base hospital, these should at once be

replaced by some other form of splint. For the arm and the thigh I believe, whenever the positions of the wound allow of its application, that none can surpass the spring extension apparatus of Delbet; in the leg one should leave the foot free as soon as possible by applying Delbet's walking plaster splint.

I know of course by experience that because of the presence of inflammatory troubles one cannot always do what is most desirable, that infective complications often upset our plans. But in most cases it is possible to apply if not the most ideal apparatus, at least the second best. I must, however, keep to general principles, since the technique of the application of splints does not fall within the scope of this book.

In the upper limb, as I have said, stiffness of the fingers and shoulder is often due to the abuse of immobilisation even in a sling. In the lower limb the most frequent and the most disabling lesion is talipes equinus with slight varus—the fixation in extension of the ankle joint—but the common cause of this is rather a lack of immobilisation. Two types of cases have to be considered, according as the wound occurs in the foot or in some other part of the lower extremity.

When a focus of bone and joint suppuration occurs in the foot, if the wounded man be left to himself to adopt what attitude he please, he will lie most often on the affected side (the limb lying externally rotated), sometimes, however, on the sound side (the limb in internal rotation), but in either case he will bend the knee and plantar-flex the foot. In this position the muscles are relaxed, and the weight of the bedclothes is avoided.

During the acute phase, whilst the foot is inflamed and swollen, whilst the wounds are still open and profusely discharging, we are often forced to leave things as they are. But as soon as it is possible we should, under an anæsthetic, immobilise the foot at a right or slightly acute angle in an interrupted plaster splint, and ankylosis, almost inevitable in the circumstances, will occur in a good position.

Lesions of the leg and thigh in which originally the foot is quite normal end too often in a fixed position of equinus; this position is especially to be guarded against in cases of fracture; but it is not uncommon following simple flesh wounds, even an aseptic bullet track. In these cases the instinctive attitude of rest and ease, as in the former case, consists in lying on the sound side, with the knee flexed and the foot dropped; contraction and then retraction of muscles come into play, the bad position becomes fixed, and finally the joint stiffens. Deep muscles often share in the contraction and the toes become clawed, which considerably adds to the functional troubles. One must not imagine, moreover, that the deformity can be avoided by getting the patient up; a fruitful cause of permanent talipes equinus or drop foot is the too early permission given to men wounded in the leg to get about on crutches. Fearful because of pain or inconvenience of putting weight on the foot, they flex the knee and let the foot drop.

In bed, lying on the sound or on the wounded side, they adopt the same position, which is thus maintained fixed both night and day. When the wounds are healed and free from pain, the knee movements almost always return quickly, but the drop foot persists.

From this knowledge of the cause one can easily

deduce the necessary preventive treatment: make the patient lie on his back, the knee fully extended; keep the weight of the bedclothes off the foot by a cradle; keep the foot up by means of an ankle strap or a bandage the moment the least tendency to drop the foot is detected, and do not hesitate to apply a plaster if this simpler means does not suffice to maintain the ankle joint in good position; allow walking only when it should be possible without crutches, at first with two sticks and later with one; see that the patient keeps the sole flat on the ground, and, if necessary, retain for a time the plaster splint during walking.

It is better to prevent than to cure, for in bad cases it is a deformity most difficult to cure. This "foot drop" due to the contraction of muscles is different from the talipes equinus that results from muscular spasm, which also, however, is both frequent and difficult to cure.

In many wounded, contractures occur which are out of all proportion to the severity and out of all consonance with the position of the wounds. Clinically they are to be differentiated from cases of paralysis in that by persuasion—sometimes, it is true, rather forcible—the patient can be got to execute slight movements of the toes or even of the foot; from cases of contraction, in that the muscles of the leg retain their size and normal movement, and the intermuscular and subcutaneous connective tissues and the skin are quite sound. The deformity of the foot is more varus and less equinus than in these cases. Under chloroform the foot at once moves normally.

Similar phenomena occur in the upper limb. They seem to belong to the category of functional con-

tractures or traumatic hysteria, and it is often very difficult to differentiate them from organic lesions, from a true neurosis, and even from malingering. But sometimes, in cases in which the patient is certainly not malingering, after an easy correction under chloroform has been effected the deformity recurs immediately after removal of the plaster, in spite of all attempts at suggestion. It is probable that, in these cases, a much earlier manipulation under chloroform, as soon as the earliest signs of the contracture appear, would produce more permanent results.

B. *Curative Treatment*

1. *True complete Ankyloses.*—It is convenient to consider under this heading all cases of intra-articular bony or firm fibrous ankylosis, as well as of the much rarer extra-articular bony ankylosis. I have seen a good number of such cases treated by ignorant persons by mechanotherapy. And yet it is not at all difficult to appreciate with or without an anæsthetic whether or not movement is absent, to ascertain what has been the nature and degree of severity of the causative arthritis, to verify the existence of bony ankylosis by an X-ray plate. Let us leave, then, these too frequent mistakes in diagnosis to consider the only possible treatment of these cases of complete ankylosis, viz. orthopædic resection, or in some special forms, orthopædic osteotomy. The indications for these operations, subject of course to the restrictions put upon us by the fear of recrudescence of bacterial activity, are exactly as we knew them in civil surgery, of a purely mechanical nature, and quite independent of the pathological cause of the disability.

Hence for ankylosis in flexion and adduction of the hip joint one will have recourse almost exclusively to sub-trochanteric osteotomy. In the case of the other joints resection with the object of getting ankylosis in good position in the lower limb, in the upper limb with the object if possible of regaining at any rate some of the previous range of movement.

Hence in the lower limb one will operate only in cases of ankylosis in bad position; and in such cases resection of the knee joint, astragalectomy, transverse or cuneiform tarsectomy of the front part of the foot give much better results than does orthopædic apparatus.

In the upper limb I have seen no case of malposition of the shoulder so bad as to require operative interference; ankylosis nearly always occurs in slight abduction. It is in the case of the elbow joint, almost exclusively of the joints of the upper limb, that operative intervention need be discussed, and I repeat that, in my opinion, except in certain special occupational conditions, the best position for ankylosis is at a right angle, the forearm in supination or halfway between this and pronation. Complete pronation renders a limb ankylosed at a right angle almost useless, and will hence require osteotomy of the radius. On the other hand, it is supination that interferes with the utility of an elbow fixed at an angle of 135 degrees. When the elbow is fixed between 135 degrees of extension and full extension the functional result is deplorable.

As regards fibrous ankylosis of the elbow joint in a bad position it is almost always possible—so much does this joint lend itself to a good grip and leverage—to break down the adhesions by force. In doing

this I have, however, extensively torn a scar involving the skin and muscles at the back of the joint, without thereby interfering with the desired correction of the deformity.

If the ankylosis of the elbow joint is bony, and it is considered that the position requires correction, resection of the joint should be performed ; but where one is aiming at the production of a ne-arthrosis at once stable and possessing a good range of movement, the sub-periosteal orthopædic method of Ollier should be attempted, but not until very late, long after final healing has taken place.

By this method it is certainly possible to obtain a stable movable joint, but this does not result with quite sufficient constancy to make one inclined to attempt it in cases of ankylosis in good position.

In my experience, operation for ankylosis of the wrist joint is hardly ever indicated.

2. *Stiff Joints and Lesions of Muscles and Tendons.*—In cases of stiff joints and the disabilities of tendons and muscle that accompany them, the following methods of treatment possess indications and give excellent results when prescribed for suitable cases :—mechano-therapy, mobilisation, massage, hot baths, and electrical treatment ; but the special indications for each of these methods are not as easy to specify as some writers make out.

(*a*) In the first place, there are varieties of stiff joints in which all these methods are quite useless. Where the range of movement of a joint is mechanically limited, not by any pathological condition inside the joint itself, but by the presence of a particular mass of callus or an inflammatory hyperostosis, we diagnose a "stiff joint," *i.e.* an incomplete ankylosis with

partial retention of mobility. Now in such cases mechanotherapy is just as ineffective as if complete bony ankylosis were present ; the only effective treatment in such cases is the resection of the offending mass of bone wherever this is possible, and when such a course is justified by the functional disability or the presence of serious mal-position. Such a state of affairs is extremely common in badly reduced and mal-united fractures of the lower end of the humerus. These cases, in which the real cause of the disability—deformation of bone—is easily established by radiography, or even on palpation, are characterised on clinical examination by the definite inelastic arrest of passive movement of the joint.

Secondly, mobilisation and massage are harmful in their effects in the presence of inflammation in the tissues ; such inflammation should be considered as contra-indicating the use of these means of treatment even in cases of joint disability that would otherwise benefit from them. Signs of inflammation may be quite absent in the joint itself, but present at some more or less distant part of a neighbouring bone in which union has been complete and the suppuration ceased for a considerable time. Even in such cases massage of the muscles round the bone and daily manipulations of the joint should still be regarded as contra-indicated. Such treatment too often results in a return of pain in the bone and a re-opening of the sinuses. If such a joint be fixed in a good position, and nothing done in the way of manipulation, it will often slowly regain a considerable range of movement of its own accord ; if fixed in bad position, it will be necessary to perform forcible correction followed by immobilisation in good position for three or four weeks.

In order to judge of the necessity for this we must be guided, not by the range of movement that still exists, but by the direction in which such movement is possible—*e.g.* such correction will be necessary in elbow and ankle joints that will not flex to a right angle, in knee joints that cannot be fully extended.

(*b*) The correct treatment for stiff joints is "mobilisation," hot baths and massage constituting important accessory means of treatment. Our aim should be to obtain return of movement, at least in the directions that we have just specified for each joint.

If the joint is fixed in bad position, *i.e.* if it is impossible for the joint to adopt the "position of election for ankylosis," one should, as a general rule, commence by increasing the range of the movement opposite to that which it is desired to increase; in other words, the position of the joint that it is desired to correct or avoid should first be exaggerated, *e.g.* flexion of hip and knee joints, extension of elbow and ankle joints should be increased. After gaining a certain increased range in this direction, one should then proceed to manipulate the joint in the opposite direction, thereby gaining at each manipulation an increase of so many degrees. When the position of election is reached, or as great an increase of range obtained as is possible or desirable, the joint should be immobilised, fixed in this position for a while by some means or other.

The practical realisation of this principle varies, of course, with the particular method of mobilisation adopted, and the choice of this depends on the pathological and clinical variety of the lesion.

The various methods are:—

1. Mobilisation in stages by repeated manipulations.

2. Forcible correction and mobilisation.
3. Correction by successive plasters.

It is often useful to combine two or all of these methods in the treatment of a particular case.

I. Gradual passive mobilisation in successive stages can be carried out in three different ways :—

(1) Manual manipulation performed by the surgeon or masseur.
(2) Passive movement executed by the patient himself.
(3) Mobilisation by mechanically moving apparatus, which, taking firm hold of the joint, forces it through its own range of movement.

This last method, *mechanical mobilisation*, has during the past twenty years come much into vogue, and many special institutions have been furnished with most interesting-looking apparatus by means of which any joint can at will be put through any movement or combination of movements.

But the results in practice have too often fallen short of the hopes and promises of theory. In many cases, in order to avoid pain, or even to save himself trouble, the patient, giving no particular attention to the exercise, keeps working away at the instrument quite mechanically, like a beggar grinding a barrel-organ, in which cases, of course, no improvement occurs. When force becomes necessary, the apparatus, working blindly and mechanically, cannot be regulated with any precision so as to suit the necessities of each particular case; and where the stiffness resists ordinary manual mobilisation, it is much better to have recourse, at any rate for the first stage of treatment, to forcible correction under an anæsthetic.

Gradual mobilisation by the surgeon or by a masseur under full supervision—which, in the case of many masseurs, who are no more than presuming empirics, is very necessary—constitutes the method of choice; in adaptability to the varying circumstances and conditions of different cases no other method can rival it.

Such treatment cannot be, should not be, regulated by any arbitrary rules as regards the duration, vigour, or frequency of its application. Long experience is necessary in order to know, from the degree of intensity of the inflammatory reaction, exactly when and in what cases such treatment should be persisted in or suspended.

Pain is almost inevitable whenever, a movement having attained its limit, it is forced further and the pressure maintained for a few seconds or minutes in order to gain ground. No matter how acute this may be, it is not its intensity but its duration that is important and significant. If the pain ceases as soon as the tension on the limb is relaxed (often, however, it ceases earlier), then it should not be regarded as contra-indicating immediate persistence in the mobilisation.

On the other hand, if it lasts beyond the point of relaxation of the force, even if it be less severe, the masseur should defer for the time being all further manipulation, and before recommencing the treatment on the following day he should be most careful to ascertain that no localised points of tenderness to pressure, no swelling or heat, or no redness (as sometimes occurs) are to be detected.

Such signs are those of a recurrence of inflammation in the joint, and according to their intensity it will be necessary either to increase the interval between the

"séances," or to suspend such treatment altogether, and even to resume for a time immobilisation in the position of choice. Often when mobilisation by manipulation is originally decided on, the surgeon has been unable to decide definitely whether or not the joint inflammation has entirely and finally subsided; in such cases treatment supervised and graduated as we have described will very soon settle this doubtful point.

Such treatments under the supervision of the surgeon are necessarily given at intervals, at most once a day; it is, however, most useful to teach the patient in addition exactly how to hold the limb so as to maintain and how by active and passive movements to use it all day long so as to improve even the position gained by the previous manipulation.

I cannot describe all the details of such active and passive movements as are suitable for each particular joint; but several examples will serve to illustrate the general principles, the practical application of which will vary considerably with intelligence and determination of the patient.

Let us take as a short example a case of stiff fingers: the patient can actively flex these very easily and simply by grasping in the palm a cylinder of variable diameter; it is also very easy for him passively to force each finger separately and successively into a position of flexion, and to maintain it there for several minutes.

In the lower limb, in a case of contraction of the tendo Achillis, for example, the patient should plant the foot flat on the ground and execute an active flexion of the knee joint without allowing any elevation of the heel off the ground. This inevitably

results in passive flexion of the ankle joint, rendered possible by the relaxation of the gastrocnemius. This movement, which should be frequently repeated during the course of the day, is the same as that by which in normal walking we prepare to lift the foot from the ground, rolling the foot from heel to toe on the ground and then raising the heel; as soon as the flexibility of the ankle joint increases so that the foot can approach a position at right angles to the leg, walking is the better for the performance of the corrective exercises, carefully supervised to see that the whole extent of the sole is kept flat on the ground at the precise moment when the corresponding limb is vertical and in full extension.

This, then, is an example of the re-establishment and improvement of movement in a joint actually by the exercise of that joint. As a matter of fact many stiff joints become free and supple by the performance of their normal movements by the patient himself on resuming his ordinary work.

This is true as regards limbs that are stiff in a good functional position, and even as regards those in slight mal-position. And I am not sure—not any surer than I am in connection with similar cases in the accidents of civil life—that in these clearly specified conditions mechanotherapy has a good or favourable influence in the case of a wounded man, who goes on for months keeping his limb in one position, and is sometimes in no hurry to be cured.

Quite a different state of things obtains, however, if there be present some considerable degree of deformity or disability—spontaneous correction is then impossible. Before attempting to gain an increase of range of movement of such a stiff joint—or

in some cases leaving it to ankylose completely—the surgeon should always commence by getting it into good position.

II. *Forcible correction*, often useful in order to gain time, is absolutely essential for the initiation of movement in cases in which the immobility is absolute or almost so. It is necessary, in fact, to start by getting a sufficient angular movement to allow the leverage that we are able to exert in manipulations to be efficient.

The operation consists in the forcible manipulation of the joint through the alternate movements of flexion and extension (or, in the case of the shoulder joint, the movements of abduction and then circumduction) in the order we have already specified, and in forcing them to the full extent possible at one sitting, as much time as is necessary being devoted to this purpose.

Judging by the accounts of patients in whom by a trick of the thumb we have suddenly forced into full flexion one or more fingers fixed in extension, it is an extremely painful operation. The pain is extreme, but of short duration; the more stoical of patients can bear it without an anæsthetic, whilst it can often be inflicted suddenly on others by taking them off their guard. It is impossible, however, to perform such an operation without the aid of an anæsthetic in the case of one of the larger joints, where the manipulation will certainly be hard work. In these circumstances ethyl chloride or chloroform should be administered, according as the operation will take a short or long time (the latter is usually the case with the instep, the former with the elbow).

One is often struck, especially where, as in the case

of the fingers, no anæsthetic has been used, by the almost complete absence of pain on movement immediately after the first very painful manipulation is over.

Following the operation, bruising and swelling are usually apparent and well marked, thus proving the rupture of vascular adhesions that we have produced, and that the various crackings in and around the joint heard and felt during the correction led us to anticipate. But real inflammatory reaction is either but slight or altogether absent: the fingers should be left completely free to move, and the same day the patient should be encouraged to work them gently; a larger joint—*e.g.* the elbow or knee joint—should be kept at rest in good position for a day or two compressed by a firm, soft bandage.

If the correction has necessitated violent manipulation, and if for this reason one is led to expect considerable swelling—œdema and bruising—and especially if one suspects the possible occurrence of a revival of latent inflammation, it is best to immobilise the joint in plaster, perhaps for a few days only, perhaps for three or four weeks in cases on which a return of the stiffness, or even possibly definite ankylosis, seems possible, the joint thus being kept in a good position so as to prepare for such an eventuality. Complete immobilisation is in addition, in these circumstances, the best means of arresting the inflammation, and so of preparing the stiff joint for a later and further attempt at correction.

It may be said that forcible correction is successful in almost all cases of stiffness of joints properly so called, even of joints in bad position, and in all cases of peri-articular adhesion of tendons. If, however,

the correction of the position of the limb is not complete, we should have recourse to the following method :—

III. *Correction by a Succession of Plasters.*—Where a joint is fixed in bad position, and especially where it is considered that the inflammation has not quite subsided, correction in stages—an old classical method in orthopædic surgery—often gives excellent results. At each sitting, and without an anæsthetic, as much correction as can be obtained without producing pain is maintained either by manual pressure or else by elastic traction, until the joint is immobilised in plaster in this new position. In this way the fibrous and muscular elements concerned in the contracture are subjected to a continuous tension, *e.g.* the extensors of the elbow and ankle joints, the flexors of the knee. These, which would resist a sudden, even violent attempt at full correction gradually relax under this continuous pressure, and the joint thus gains a little of its former range of movement in this particular direction ; at the end of a fortnight a further increase is gained either by the application of a new plaster altogether, or else by cutting the original one at the level of the joint and filling up with new plaster bands the gap thus produced at the angle of the plaster on the side away from which the joint is being moved.

This method of gradual correction by successive plasters may be compared to that obtained by the spring apparatus of Pierre Robin, who has adapted it to the principal axis of movement of each of the joints. This is worn constantly, and in this way a really strong continuous elastic traction is maintained on the contracted tissues. Considering the method of con-

struction of this apparatus, however, I do not think that it will be of much use in the treatment of bad positions of paralytic origin. But certainly it may be used with great benefit in cases of a moderate degree of stiffness, particularly in the correction of a fixed position of talipes equinus.

An apparatus with elastic traction is most useful for maintaining the corrected position.

IV. *Preliminary Operations.*—These include tenotomy, tenoplasty, and sometimes division of ligaments, a description of the technique of which does not fall within the scope of this book. These operations are indicated when in an anæsthetised patient a tight tendon or ligament can be established as the cause of failure to obtain further correction of a deformity, hence the indication for their performance is often apparent only during forcible correction under an anæsthetic.

They are specially indicated in the foot, *e.g.* the division, or better the elongation, of the tendo Achillis for the correction of a fixed position of equinus. But in war surgery unforeseen failures are common ; the sclerosis of the posterior muscles of the calf and of peri-articular fibrous tissues is often very widespread, so that immediate correction often gives an imperfect result, and relapse is not uncommon. There seems to be present in some of these cases an extensive complicated pathological condition comparable, as I have already pointed out, to the ischæmic fibrosis of Volkmann's contracture of the forearm muscles, and it is common knowledge that the operative treatment of this condition involves the freeing and lengthening of many tendons with complicated plastic repair of their sheaths.

The alternative procedure is to shorten the bones which have become too long for the shortened muscles. This result is obtained in the forearm by resection of portions of the shafts of the radius and ulna. In the foot the corresponding operation would consist in complete or partial astragalectomy, a procedure in many cases followed by firm ankylosis in good position.

True arthrodesis is indicated in paralytic drop foot, but this is frequently complicated by the development of permanent contracture in the muscles of the calf similar to that in the cases we have just been describing. If the foot is quite flail, arthrodesis of the sub-astragaloid and mid-tarsal joints should be performed. The ankle joint should be stiffened in addition only if there is complete loss of power below the knee joint.

V. *Accessory Means of Treatment.*—These consist of :—

Massage is useful in softening and stimulating the circulation of the tissues about a stiff joint, and in restoring and developing atrophied muscles. For this latter purpose it is more efficacious than electrical stimulation, especially if it be combined with resisted exercises. It is useless in cases of diffuse muscular sclerosis.

Hot baths, if the treatment be prolonged, certainly assist in the mobilisations of joints. Whilst in the bath the movements, both active and passive, can be performed with less difficulty over a greater range and with less pain. Practically all hydrotherapeutic centres advertise this method of treatment : no doubt after the war such advertisement will be increased. It may seem surprising to some perhaps that all these places claim that the advantages gained by this

treatment are due to the special minerals of the different waters. Most probably the rôle of the minerals is quite accessory and the benefit is due chiefly to the heat, perhaps to some extent also to physical and chemical phenomena, the existence of which we are just beginning to realise, occurring in these waters. These seem to be at a maximum in the mud of certain hydrotherapeutic centres; as a matter of fact, for a great many years I have held that for non-tuberculous varieties of chronic arthritis with stiffness and mild attacks of inflammation, treatment with mud baths is best at those centres where in addition they have thought of installing departments for massage, mobilisation, and electric treatment.

CHAPTER V

THE EFFECT OF MAL-UNITED FRACTURES ON THE ACTION OF NEIGHBOURING JOINTS

I HAVE thought that it would be useful to group together in this chapter certain rudimentary principles with which we are concerned in the study of the normal and pathological mechanics of the bones and joints.

Whenever, after the union of a fracture, the working of a neighbouring joint is interfered with and the range of its movement limited, it is usual to diagnose "ankylosis of the joint." When it is clearly established that the normal range of movement of the joint is definitely limited, such a diagnosis is of course quite correct. This does not, however, necessarily imply that the joint itself has lost anything of its potential former range; as a piece of mechanism it often remains in itself perfectly normal, nevertheless its physiological action has become abnormal; and in order to restore in such a case the previous range of function, the surgeon has to deal not directly with articular structures, but with a pathological condition that is completely extra-articular.

The rationale of such articular disabilities following fractures is really much less difficult to understand

than "mathematico-phobes"—so numerous among medical men—seem to think; these disabilities are due to the displacement *en masse* in any direction of a joint that in itself remains perfectly normal. From this there necessarily results a displacement or change of its field of action which is increased in the direction of the articular displacement, diminished in the opposite direction; and the physiological problem before us is to ascertain in each case in what way such a change will affect the usefulness of the limb.

A joint may be regarded schematically as composed of a fixed rod (in the limbs always the upper bone or bones) with which articulates a lower movable lever. These, like all solid bodies, bear a definite relation to the three primary planes of space :—

(1) The vertical transverse,
(2) The vertical antero-posterior, and
(3) The horizontal.

These are the geometrical terms which correspond to the anatomical :—

(1) The frontal plane,
(2) The sagittal plane,
(3) The horizontal plane.

Since in anatomy the body is always regarded as vertical, the upper limbs hanging in complete supination and the long axis of the foot in the sagittal plane, we must regard this schematic joint that we are about to study as being similarly placed, *i.e.* with the axes of the two levers (the fixed and the movable) both in the sagittal plane, and the transverse axis of the joint between them horizontal. This, then, is the

position of the axes of the schematic limb in repose, the movable lever lying in the position from which it starts its movements, whose range may be measured in degrees, and which we may call flexion and extension in the sagittal plane, adduction and abduction in the frontal plane, rotation in the horizontal plane around the long axis of the limb, which remains vertical.

Now when this joint is displaced in its relation to the rods by a kink or bend occurring in one or other or both of these its axis undergoes a change of plane. From such a displacement *en masse* of the joint itself, unaccompanied by any change in the articular elements or in the actual range of its potential movements, there results a change to new planes of movements of the rods themselves, and the practical question that arises is to determine accurately under what conditions these modifications of the action of the joint limit movement in useful directions, thereby diminishing the functional utility of the affected joint.

I will take as an example the simplest case, that of a hinge joint represented graphically by a transverse bolt at right angles to the two articulating rods, one mobile the other stationary. Using the arbitrary positions in space that we have adopted, we see that this joint possesses but the movements of flexion and extension. It is the type of the knee and elbow joints.

The most complicated form of joint, from the point of view of planes of movement—the ball-and-socket joint—possesses movements in every direction, including that of rotation. Of this form the hip joint is the type; we will study it later, especially in its relation to the movement of rotation and the analogous movements of pronation and supination.

A. The Effect of Mal-union on Hinge Joints

Suppose A B C to be a hinge joint, with C B fixed and movement of A B round B taking place forwards only. The point A turning round the point B describes the circumference of a semicircle, ending by becoming superimposed on the point C, having passed through 180°.

Fig. 101.

Fig. 102.

Fig. 103.

These two lines C B and A B determine a plane in which this movement of A B takes place. Let us regard this plane as coinciding with the sagittal plane of the body, and then see what takes place when the joint is displaced *en masse* by a kinking of B C. First in the frontal plane, second in the sagittal plane, and third in the horizontal plane. From the study of these the consequences may be readily deduced when the bending of B C takes place not in one but in simultaneous combinations of these three planes.

(*a*) *Transverse Displacement of the Joint* or dis-

placement in the axis of the joint itself by angulation in the frontal plane of the fixed rod B C at the point D, forming either a right angle (fig. 102) or an obtuse angle (fig. 103).

Displaced thus, though unchanged in itself, the joint has lost its former axis with reference to the fixed rod C D. Its plane of movement will always be sagittal, but will now correspond to the line A B and no longer to the line C D. The super-position of A and C is now no longer possible; the point A will always be separated from C by a distance equal to that of D B. Hence we have displaced by this distance inward or outwards, to the right or to the left, the plane of movement of the joint, and whenever A B is flexed to 180° the point A will coincide with the point A along the prolongation of the line A B.

Where D B is oblique and not at right angles to C D, the amount of displacement of the plane of joint action will correspond to the projection D H.

The amount of this displacement is independent of the distance from the joint of the point D of bending, independent also of the length of the movable lever.

The range of movement—flexion—possible also remains unchanged, as the lever A B can still pass through 180° to take the position B A .

In normal anatomy one sees this phenomenon exemplified, in relation to flexion and extension of the hip joint, in the angle that exists between femoral shaft and femoral neck.

Here the neck is doubly oblique, and the plane of the displacement correspondingly so, but the mechanical principle remains the same. The movements of flexion and extension of the shaft takes place not in the sagittal plane of the femoral head, but in a

sagittal plane some distance external to it: this does not at all affect the relative range of flexion and extension of this joint, but other things being equal and in accordance with a mechanism that I shall describe for sagittal displacements, it adds to the field of adduction at the expense of that of abduction.

In the pathological condition of fractures a similar phenomenon occurs in those transverse displacements, in the extreme form of which the lower fragment slides up to lie along one or other side of the upper; the longitudinal axis of this lower fragment is thus displaced sideways to the extent of its own thickness; an analogous but rare state of affairs arises when in a double fracture the middle fragment lies more or less obliquely, so that the whole doubly bent lever becomes bayonet-shaped (fig. 104).

FIG. 104.

In such cases the amount of the displacement is small and of but little practical importance; what is important in such cases is the shortening that has taken place.

(*b*) *Sagittal Displacement of the Joint, or Displacement parallel to the axis of the Joint.*—Let us refer again to our diagrammatic articulation, let us conceive the fixed limb as bent at D to an obtuse angle α, which lies on the side of the two levers opposite to that on which movement of the joint takes place, and the new axis B D as prolonged to B A downwards from the bend at D (fig. 105).

The joint B in itself has undergone no change, but in relation to the axis C D it has moved to the extent of the angle α.

The position of A″, the new starting point of the movement (0°), is that where the rod A B lies in a straight line with B D; the end position of movement (180°) is that where B A′ is superimposed on the prolongation of B D, but this remains separated from D C by the angle β, the supplement of the angle of bending α. The range of movement remains unaltered in relation to the real axis B D, but in relation to the axis D C it has increased in one direction and towards one limit of the 180° of range, *i.e.* towards A″, and decreased to a corresponding amount at the other end, *i.e.* towards C′. Now if movement within the field represented by the angle A′ D C is functionally important, and in the field represented by the angle A B A″ of no practical use, the net result is a clear decrease of the range of usefulness of the joint.

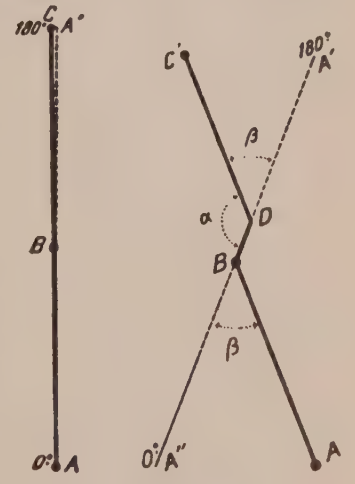


Fig. 105.

This loss is directly proportionate to the distance which still separates the free extremities of the two articulating rods when movement towards each other has come to an end. Hence it is greater the nearer the bend or kink is to the point of articulation.

With the angle C D A′ equal in both, the triangles C D A′ are similar; hence the longer the side C D, the longer also in proportion will be the side C A′ (fig. 106).

This geometrical diagram may be applied exactly

to our hinge joints, of which the best example is the elbow, when a transverse fracture of the lower extremity of the humerus unites at an angle with persistence of the backward tilting of the lower fragment.

In the elbow, normal flexion has a range something short of 180°; it is limited by contact of the soft parts of the forearm and arm. Functionally, however,

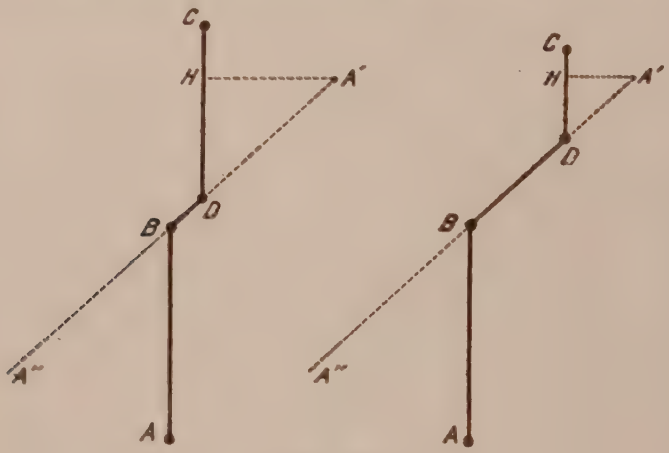


Fig. 106.

flexion should be regarded as complete only when the patient can scratch the front of the shoulder with the tips of his fingers; if the flexion falls short of this, we should diagnose a limitation of the full functional capacity of the joint, and technically the condition becomes one of ankylosis. The joint itself, however, remains quite intact and normal, but its movements, still of a potentially normal amplitude, have lost some of their functional usefulness, which exists only in relation to the long axis of the humerus; they are increased in the direction of hyperextension of the

joint, an increase of no functional significance whatever ; they are decreased in the direction of flexion—a most prejudicial decrease from the functional point of view. In other words, flexion has been handicapped from the commencement, and by the time movement is complete it has not made up its handicap.

The typical case often met with is that in which, the joint remaining normal in itself, careful clinical examination establishes the existence of a negligible degree of hyperextension. But if because of some additional articular lesion extension also is diminished, that does not of course alter the diminished flexion. The paradoxical condition may even occur in which, the forearm at the full limit of its extension lying in a line with the long axis of the arm, extension although practically normal is yet mechanically diminished (by articular lesion), whilst flexion mechanically normal (unaffected by such articular lesion) yet practically falls short of the normal.

The same thing happens in cases of Colles's fracture of the lower end of the radius, in which union has occurred with persistence of the backward tilting of the lower fragment, giving rise to the so-called " dinner-fork " deformity.

The normal movements of the hinge joint of the wrist take place in the two directions of flexion and extension in relation to the long axis of the forearm ; the point of commencement of both these two movements—the position of zero in the geometrical scale of these two movements—is the position in which the long axis of the hand lies in the direct prolongation of the long axis of the forearm. If, then, the lower fragment has united in a position of backward rotation round the transverse axis of the fracture, *i.e.* slopes

backwards and downwards when the long axis of the hand lies in the line of this fragment of the radius, it will make with that of the forearm itself an obtuse angle open behind; this constitutes an attitude of extension, the degree of extension being proportionate to the supplementary angle of this obtuse angle; consequently, unless the wrist joint by an increase in its suppleness extends its normal range of movement, flexion will to a corresponding degree fall short of its normal.

In this fracture, the radius being shortened because of the impaction whilst the ulna retains its full length, it is the rule for the hand to become displaced outwards into abduction; the range of abduction is thus increased, and that of adduction diminished; but there is, in addition, a horizontal displacement due to an inclination of the normal axis of the joint. Such will be considered later.

We have described, as regards these displacements, their usual form in each fracture, that of backward tilting of the lower fragment towards the direction of extension of the joint.

Exceptionally in the case of the radius, very rarely in the case of the humerus, union occurs with the lower fragment tilted forwards in the direction of flexion; in such cases the range of flexion is increased and that of extension diminished.

Such a state of affairs occurs in certain fractures of the lower third of the leg where union has taken place at an obtuse angle open forwards, the lower fragment sloping obliquely downwards and forwards. In such circumstances, with the foot at right angles to the leg and the knee straight it becomes impossible to plant the sole flat on the ground; when

the femur and upper fragment of tibia are vertical and the heel on the ground, as long as the ankle joint is held at a right angle it is quite impossible for the sole to come into contact with the ground, and the patient has inevitably to walk on the heel unless he resorts to one or two possible methods of compensation, either to flex the knee and then of course the hip (fig. 107), or else to drop the foot into a position of equinus,

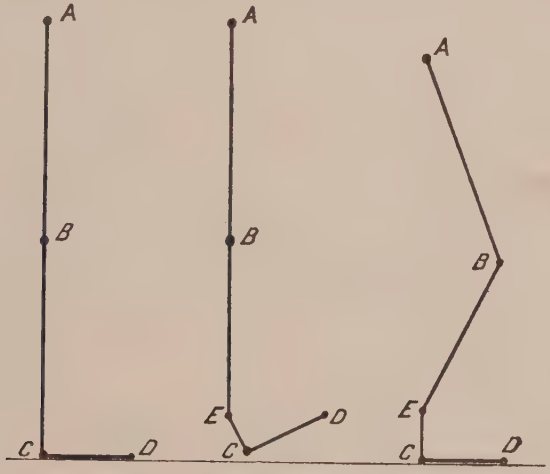


FIG. 107.

the latter method, however, limiting to a corresponding degree the natural rolling of the sole of the foot on the ground during walking.

Union in the opposite direction, the lower fragment obliquely sloping downwards and backwards, sometimes happens, in which case, when the foot is at right angles to the leg and the fore part of the sole on the ground, the heel remains in the air and the foot in a position of equinus, although the range of flexion of the ankle joint still remains normal. Slight cases of this disability in the absence of any articular

lesion gradually develop an increased range of flexion of the foot, which thus compensates for the limitation of flexion we have just described. In severe cases either the patient has to walk on the fore part of the foot, which, unless compensated for by the existence of some shortening of the limb, is most inconvenient and awkward, or else he develops a progressive hyper-extension

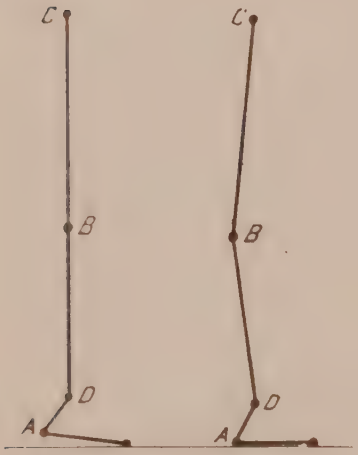


Fig. 108.

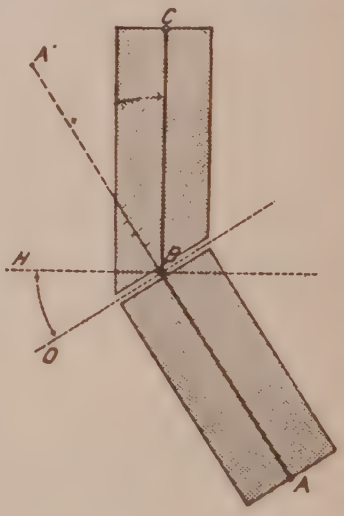


Fig. 109.

of the knee joint, which, if he persists in walking with the sole flat on the ground, in the end becomes a real compensatory genu recurvatum (fig. 108).

(*c*) *Horizontal displacement* by an abnormal inclination of the axis of the joint.

The joint A B C is viewed from the front and represented in its breadth so as to show the obliquity of the axis; the lever A B must always move at right angles to this axis, hence, this axis being oblique, it moves obliquely in relation to the bar B C. The

plane of movement hence is no longer sagittal, and on flexion the point A comes to lie at the point A′ away from C on the side opposite to that to which the obliquity of the articular axis has displaced the free end A of the lever. The angle of deviation of the lever A′ B C is equal to the angle of deviation of the articular axis H B O. The absolute amplitude of the displacement (A′ C) depends on the length of the lever (fig. 109).

This case is not, then, an example of a simple angulation of the bone, but that of an elongation of one side of the fixed bone lever, the other side retaining its original length. Such a state of affairs occurs in supra-condylar fractures of the humerus united in varus; in such, flexion of the elbow joint, often of normal range, carries the hand well to the outer side of the shoulder, and the hand approaches the mouth only by a combination of abduction with internal rotation.

B. The Effects of the Mal-union of Fractures on Ball-and-socket Joints

The hip joint is an example of a ball-and-socket joint which not only allows of movement in all directions, but also permits, by an association or combination of these various movements following one another in rapid succession, the further complex movement of circumduction.

(*a*) By reason of the angle that exists between the femoral neck and the femoral shaft the hip joint is, so to speak, displaced inwards; and since the neck of the femur slopes downwards, outwards, and slightly forwards, the effect of this displacement is correspondingly complex.

The mechanism of this joint may be easily understood if one considers the movement that takes place in each plane as the movement of a hinge joint. As these planes are, for flexion and extension the frontal plane, and for adduction and abduction the sagittal, one will readily comprehend that this natural displacement of the joint places a slight handicap on

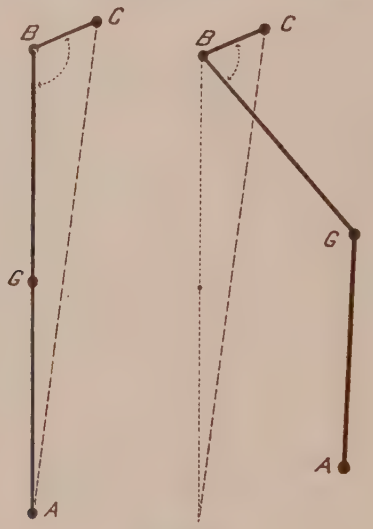


Fig. 110.

flexion—normally so important a movement of the joint—and a great handicap on adduction.

Any decrease, then, in the femoral angle at B will displace the shaft further into adduction, consequently will diminish the range of abduction. Every increase in this angle will have the converse effect (fig. 110).

(*b*) As regards rotation, let us commence by studying its effects in the case of a straight lever.

Suppose we erect a vertical axle rotating on pivots

at its two ends, one of which rests on the ground. Regarding this as representing a human limb, and as standing in the sagittal plane, let us fix to each end of it half a crossbar, each of which also occupies this plane, so that the whole (leaving out of consideration for the moment the femoral angle) represents a lower limb, and the lower half crossbar, resting on the ground, the foot.

Suppose now we cut this axle across at any point between the level of its two crossbars and rotate the lower segment a slight distance round its vertical axis and then rejoin it to the upper in this new position; now whenever the upper crossbar lies in the sagittal plane at the position of 0°, the lower will make with it an angle proportional to the amount of the rotation either inwards or outwards, and in whatever direction and to whatever extent the whole be now rotated, this constant angle between the readings of the degrees of rotation of the two crossbars will remain.

Such a condition as is here represented sometimes actually occurs in fractures of the femoral shaft that have united with but little or no overlapping, but in which some passive external rotation of the lower fragment has been allowed to persist uncorrected. If in such a case the amount of internal rotation possible at the hip joint still allows the long axis of the foot to occupy a plane a little internal to the sagittal, the functional disability that results is of little practical importance; even where the ability to rotate the leg and foot inwards is lost—in other words, where the long axis of the foot can just reach without passing the sagittal plane—the disability remains still practically negligible. In extreme cases, however, in which the long axis of the foot, with as full internal rotation

at the hip joint as possible, fails to reach the sagittal plane, the functional result is one of grave disability. In the first case the displacement of the lower fragment, and hence of the leg and foot, into a position of external rotation is less than the normal amount of full internal rotation at the hip joint; in the second case these two—the external rotation at the seat of fracture and the full normal internal rotation at the hip joint—are equal; in the third case the latter is less than the former, and a mathematician would say that the amount of internal rotation was a negative quantity.

(*c*) So simple and uncomplicated a displacement as we have here used as an example occurs but rarely; the displacement is usually a much more complex one, and takes place in all three of the primary planes.

Other things being equal, the functional consequence of such a displacement in rotation does not vary with the height of the mal-union; on the other hand, the higher up the femoral shaft towards the hip joint union with angulation takes place, the more serious the limitation of the range of abduction and adduction, and such angulation is the more likely to occur the higher the seat of fracture. The extreme cases of such displacement with angulation are usually subtrochanteric fractures.

If such fractures be left to themselves and neglected, without considering for the moment the element of the deformity due to the overlapping of the fragments, the shaft will be found to unite at an angle in the following manner: the upper fragment becomes flexed and considerably abducted, and slightly rotated outwards; below it the lower fragment falls passively into

a position of external rotation, and sometimes of adduction as well. That is to say, that on the occurrence of union the fragments will form a considerable angle, open inwards, and when the limb comes to hang vertically, parallel to its fellow, as long as the pelvis is kept symmetrical as regards the three planes of space and the upper fragment like that of the opposite side occupies the sagittal plane, the lower fragment of the femur (and consequently also the leg and foot) is in a fixed position of adduction and external rotation, and sometimes too in slight extension.

If the pelvis remained immobilised one can easily see that such a displacement would result in the limitation or total suppression of the range of abduction and of internal rotation. These movements should be regarded as non-existent when the axis of the limb in the case of abduction, the point of the foot in the case of internal rotation, fails to reach a vertical line passing through the head of the femur. Sometimes even such a mal-union affects the range of adduction, a disability which cannot be rectified except by compensatory tilting of the pelvis.

It is by a process of pelvic tilting, similar to that occurring in cases of ankylosis of the hip joint in malposition, that compensation for such limitation of the range of these movements is brought about, elevation of the corresponding side of the pelvis in the case of the adduction of the limb, rotation towards the sound side in the case of the external rotation. Hence will be readily understood the functional gravity of these cases in which not only is there absolute loss of abduction, but even negative abduction, *i.e.* persistence of adduction of the limb when abduction at the hip

joint has reached its limit. Correction of such adduction can be brought about only by a tilting of the pelvis, a procedure that merely adds an apparent shortening to the real shortening already existing, and always considerable in such cases.

(*d*) Such are the mechanical consequences of malunion of fractures of the shaft of the femur regarded from the point of view of the movements imparted to the lower limb from the hip joint. Let us now study those of fractures of the femoral neck, *i.e.* of the part of the femoral lever that lies proximal to its normally existing angle. I have already shown how the diminution of the femoral angle (a rare condition) affects the range of abduction and adduction.

In cases of extra-capsular fracture of the neck with impaction another variety of displacement of the lower fragment occurs, that of rotation with change of relation between the axis of the great trochanter (and hence of the femoral shaft) and that of the femoral neck.

If one looks perpendicularly downwards on to the upper end of a normal femur there will be seen a bar of bone expanded at its two ends, one forming the femoral head, the other continuous with the femoral shaft; this is represented in the diagram (fig. 112) as a straight linear axis.

In extra-capsular fractures the neck becomes impacted into the posterior part of the great trochanter; the posterior surface of the neck thus becomes shorter than the anterior, so that the cervico-trochanteric axis becomes concave backwards, as represented in diagram 112—a curved axis.

Let us now consider the mechanical results of this change. The movement of rotation of the femoro-

tibial lever does not take place round the longitudinal axis of this lever, but describes an inverted cone around the imaginary line passing from the head of the femur to the point of the heel ; that is to say, that rotation on the heel corresponds to a movement of the neck around the head, the great trochanter describing in a horizontal plane the circumference of a circle of which the neck forms the radius ; the position of commencement of the movement—the 0° of the scale of rotation—should be considered as lying a little in front of the frontal plane passing through the femoral head, since in the unrotated position—the long axis of the limb being in the sagittal plane—the neck slopes obliquely downwards, outwards, and forwards. During internal rotation of the limb the great trochanter moves inwards and forwards from this point, conversely during rotation outwards it passes outwards and backwards (fig. 111).

Let us now conceive the neck of the femur as bent to form an obtuse angle open backwards ; this will, then, place the great trochanter behind the prolongation outwards of the femoral head. This means that when the articulating end of the lever is in a position midway between internal and external rotation—the 0° of the scale of rotation—its free lower extremity is displaced into external rotation. Hence in proportion to the amount of this displacement the range of external rotation is increased at the expense of that of internal rotation, which is thus diminished, suppressed altogether, or even becomes a negative quantity.

(*e*) *The effects of mal-united fractures of the humerus on the range of movements of the shoulder joint* are from the practical point of view of but little importance.

In connection with such cases of mal-union of humeral fractures, which of course are far from uncommon, it is obvious that :—

Fig. 111.

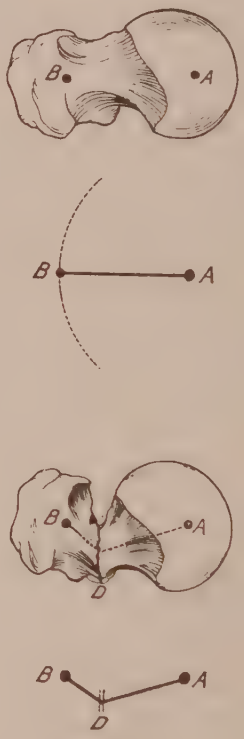


Fig. 112.

(1) Union with acute angulation of the humeral shaft outwards (a frequent variety) and inwards will diminish respectively the ranges of abduction and of adduction.

(2) Union with acute angulation forwards and

backwards will diminish respectively the ranges of flexion and extension.

(3) Union with rotation of the lower fragment in one direction around its longitudinal axis will diminish the range of rotation of the shoulder joint in the opposite direction.

All these disabilities, however, on account of the compensatory movements of the scapula that come into play, have but little functional significance, and are on the whole negligible.

If the scapula be fixed quite firmly and the humerus moved through its range of pure abduction in the frontal plane, this will be found to stop short before the arm reaches the horizontal; but when the movements of the scapula are no longer restricted, this bone tilts and so allows the humerus to reach—and even in young people to pass beyond—the vertical position. As there is normally no interference with this free range of movement of the scapula—the clavicle does not in the least restrict its power of increasing the range of movements of the shoulder joint—it will be readily understood that the loss of some degrees of abduction at the shoulder joint becomes hardly appreciable. The same applies with equal truth in the case of the movements of flexion and extension of the arm.

(*f*) *Mal-union of the Radius and Ulna resulting in limitation of the range of supination.*—Without entering into a full discussion of the details of the question—still a vexed question—of the movements of pronation and supination, we may say that the movement of pronation from the position of full supination consists of a rotation around its vertical axis of the upper end of the radius on the capitellar surface of

the external humeral epicondyle, whilst at the same time the lower radial extremity describes a semicircle from without inwards round the ulna (which, however, also undergoes a movement of its own).

In cases of complete fracture of both bones the instinctive position assumed by the patient if left to himself is one of slight flexion of the elbow joint, with the palm of the hand resting either on the bed alongside the body (the hand being in complete pronation) or else on the abdomen (with the hand in semi-pronation). Now the upper fragments of the two bones remain fixed in supination, hence the movement of pronation has taken place at the site of fracture and not at the elbow joint. If, then, this is not attended to, union of the bones will take place in such a position, and the mechanical result will be diminution or suppression of the range of supination according as the lower fragments have been kept in a position of partial or full pronation compared to the full supination of the upper.

A similar result is liable to follow fractures of the radius alone, and in these conditions an accompanying non-union of the ulna would rather serve to lessen the functional disability. It would allow of freer movement of the lower end of the ulna, which could thus rotate, instead of the lower end of the radius, whose semicircular range has been either diminished or altogether suppressed.

It must be understood that we are dealing here only with the results of this particular form of mal-union—with fixed pronation of the lower fragment—and not with the other varieties of mal-union of the bones of the forearm, angulation, shortening of the radius, the blocking up of the interosseous space by excessive

callus, or the occurrence of synostosis ; the practical conclusion to be drawn is that fractures of the forearm should be treated by immobilisation in supination, and not, as has been so often advised, in pronation or even in semi-pronation. In the gunshot fractures of the present war with extensive wounds and infective complications this is not always possible, but it is the goal at which we should aim.

Practical Conclusions

I have written this chapter, despite the dryness of its geometrical examples, because it seems to me to convey a lesson of great practical importance.

In the first place, I have endeavoured to show in the course of this chapter what care and attention we should devote to the correction of the displacements, active and passive, of the lower fragments of fractures ; pronation of the hand and wrist ; outward rotation of the leg ; backward displacement of the lower extremities of the humerus and tibia ; angulation in fractures of the femur.

And when we meet with a case in which such a mal-union has taken place, it is important that we should recognise its mechanical significance and not go on treating the limb by perfectly useless manipulation or mechanotherapy. Massage, mobilisation, heat, baths, electricity—all constitute the veriest waste of time both for the surgeon and, what is worse, for the patient. There is nothing wrong with the joint itself, and the muscles are impotent to overcome the disability.

Yet I have seen many such cases treated for long periods by these means, which are from the very nature

of the lesion useless, and all for the lack of careful clinical examination and accurate interpretation of an X-ray plate.

According to the importance of the functional disability in these cases, either leave them alone or perform osteotomy : the only treatment of the least use is to correct the axis of the bony lever. As to the exact nature of the deformity and of the correction required, their recognition will depend, in each particular case, on a knowledge of the phenomena we have described in this chapter.

CHAPTER VI

GAS INFECTION AND GAS GANGRENE

Infection with the gas bacillus of Welch, also known as the B. aerogenes capsulatus or B. perfringens, is very common in wounds sustained on the over-cultivated germ-laden soil of battlefields in Flanders and in France. Most of these wounds are shell and shrapnel wounds. The frequency of gas infection is estimated at about seventy per cent. of all cases, by Taylor (Jrl. Pathol. and Bacteriol., XX, 1916, p. 384), and it is suggestive that Fleming (Lancet, II, 1915, p. 638) found the B. aerogenes capsulatus in ten of twelve examined samples of clothing. Spores of anaerobic bacteria, notably the B. perfringens, were found by Simonds within three days after thorough and efficient sterilization in the uniforms of Belgian soldiers (La Presse Méd., No. 11, 1917, p. 100). The infectivity of anaerobic bacteria in war wounds has also been referred (Sir Anthony Bowlby) to their association with aerobic species, notably bacilli of the proteus and coli groups, and streptococci; some of the latter being facultative anaerobes.

The onset of gas gangrene may be delayed for weeks and even months after the infliction of the wound. The gas-producing bacteria concerned in the infection, essentially represented by the Welch bacillus, give rise to a peculiar type of inflammation associated with extensive swelling and a profuse wound secretion charged with gas bubbles. This inflammation may remain localized in the surroundings of the wound, especially in regions well supplied with arterial blood, the oxygen in the blood being apparently harmful to the anaerobic in-

vaders. The swelling and tension are often a cause of severe pain, until the death of the tissues results in a total loss of sensation. In favorable cases, the infection practically exhausts itself with the production of cutaneous discoloration and necrosis of the skin, whereas in the more serious infections the cellulitis extends into all the tissues, progressing especially in the muscles and transforming the limb into a huge swollen and putrid mass. Such patients usually die under symptoms of shock or collapse, within two days after the onset of the infection. The extremely rapid course of gas infection is emphasized by all observers, and death from gas gangrene of an entire limb has been known to follow in sixteen hours (Sir Anthony Bowlby, Brit. Jrl. of Surg., III, 1915-16, p. 454). When discovered and treated in time, this infection can often be prevented from developing into the highly dangerous condition known as gas gangrene.

Symptoms of Local Gas Infection.—The distal end of the affected extremity appears more or less swollen and œdematous, while the trunk and thorax are bloated, especially in the region of the chest and shoulders. On removal of the dressings (which the patient complains of as too tight) putrefying blood and pus well up from the wound, with only a few gas bubbles. Extensive destruction of fascia and muscular tissue is a feature of these cases. The surroundings of the wound often present the first degree of the characteristic yellow discoloration of the skin. Inflammatory redness and heat are absent, in contradistinction from infections with the ordinary pus-producers. The general condition is not always seriously affected.

Symptoms of Deep Gas Gangrene.—Severe pain in the wound, an extremely rapid pulse, and great restlessness, are early and important signs, usually appearing on the second or third day after the infliction of the wound. The condition can sometimes be recognized from the findings in the depth of the wound, before the

onset of external manifestations. The general symptoms become aggravated towards the fourth or fifth day. Still other cases are characterized by the premature onset of gas sepsis, with almost simultaneous appearance of local symptoms and general disturbances, taking a rapid course towards a fatal termination.

A distinction is made by Payr between a relatively benign epifascial form and a malignant subfascial or intramuscular form of gas phlegmon. The first is associated with a peculiar discoloration, first orange-yellow, then coppery red, of the swollen œdematous skin, apparently due to a diffusion of the blood pigment from thrombotic vessels, perhaps also a bloody tissue infiltration through small subcutaneous vascular ruptures. The gas infection in these cases remains limited to the skin and subcutaneous tissue, and can often be cured, with preservation of the extremity, by means of multiple incisions down to the fascia, combined with circumferential excision of the skin in healthy tissue. A transition into a chronic stage has been noted in some of these cases.

The dangerous subfascial form of gas infection spreads at an alarming rate in the intramuscular tissue interstices, transforming the flesh into a dark brown moist and putrescent mass. The skin is of a livid color, without the characteristic tints seen in the epifascial form (which is considered by some as an independent disease). The general condition is bad; sometimes icterus is present, adding to the gravity of the prognosis. Very radical measures are required to save the life of the patient, which can sometimes be done by early amputation or disarticulation of the affected extremity. The rapid spread of gas gangrene into living muscle has been referred to the peculiar anatomical structure of muscular tissue by Captains McNee and Shaw Dunn (Brit. Med. Jrl., I, 1917, p. 727).

Treatment.—The onset of gas infection in a war wound is not always equally dangerous. When the gen-

eral condition is favorable, operative interference should be restricted, whereas, on the slightest evidence of general intoxication, extensive surgical procedures are indicated. Experience has shown that the infection usually extends much higher up in the depth of the wound than can be demonstrated from the outside. Primary exposure of the higher endangered tissues has accordingly become the rule of the treatment, and offers the following advantages: It is possible to survey the extent of the infection in the proximal direction; the operator can do his work in this territory with clean instruments; the venous stasis is relieved by the incisions. The most reliable and conservative procedure in an early case of gas gangrene consists in wide exposure of the wound, with excision of the infected muscular areas in healthy tissue. The sacrifice of an entire group of muscles is often unavoidable. The after-treatment of the wound consists in swabbing with iodine tincture and packing with iodoform gauze. Other antiseptics and dressings may be employed. Gauze soaked in a 10 per cent. solution of ichthyol and glycerine is useful for packing the wound and wrapping the extremity beyond the limits of the œdema. Moist dressings with ether are recommended by Cinbridanne and Fievez (Paris Méd., VI, 1916, p. 220) on account of their stimulating action.

In the general treatment of gas gangrene, it is absolutely necessary to keep the patients warm, and their bedclothing must be arranged so as to guard against heat dissipation. An abundant supply of food is equally essential for these exhausted patients, who may advantageously be given milk as soon as two hours after an operative intervention.

Conservative measures, in gas gangrene, are assisted by "phenolizing" the wound cavities left after surgical excisions. After the use of pure carbolic acid, followed by ingestion with absolute alcohol, re-infection is prevented by embalming the wound, according to a method

of treatment recommended by Mencière (Arch. Secr. de Chir., Jan., 1917), which consists in the employment of adherent resins. The formula advocated by him is as follows:

Iodoform, Guiacol, Eucalyptol,	.....	aa 10 grams
Balsam of Peru	.....	30 grams
Ether	.....	100 grams

The wound is injected with a syringe, and dressed with gauze soaked in an analogous, but ten times more concentrated, solution.

Ether is especially recommended as an antiseptic in gas gangrene, and possesses the advantage of dissolving the infected fatty tissues adjacent to the wounds.

Indications for Amputation of an Extremity with Gas Gangrene.—Extension of the disease to the antagonists of the wounded and primarily infected muscles; progression of the gas gangrene in the muscles beyond the proximal joint nearest the infectious focus.

Summary of Surgical Treatment in Gas Infection and Gas Gangrene.—(1) In localized infections: Incisions of the infectious focus; the incision to be kept open. (2) In progressive infections: Local incisions, combined with deep prophylactic incisions for the purpose of proximal limitation of the infection. Removal of all dead or dying tissue. (3) In established gas gangrene: Distal amputation and deep prophylactic incisions, following the course of the infection. The guillotine method, without flaps, should be employed. The hyperemia bandage has been recommended, especially in Germany, as a valuable adjuvant to the surgical treatment of gas infection, in combination with enlargement of the wound. A safe rule to follow is the strict avoidance of everything that may interfere with the expulsion of the gas, including circular bandages of any kind.

Antitoxin Treatment of Gas Gangrene.—The use of an antitoxin for gas gangrene seems to be a therapeutic possibility, in the light of the results obtained by Dr. Carrol G. Bull, of the Rockefeller Institute for Medical Research, in the treatment of the infection in guinea pigs. "The indications are that early infections can be readily arrested and the more advanced and severe ones ameliorated, if not wholly checked, so that surgical interference may be resorted to with greater possibilities of effectiveness. A few cases of gas gangrene in man have been treated in which the efficacy of the antitoxin was unmistakable. The antitoxin was administered intravenously and locally about the wound."

This antitoxin is being prepared on a large scale in horses, and very potent serums have been obtained. The opinion has been expressed that it will be possible to prevent gas bacillus infections in man through a protective use of the antitoxin, and that developed cases of the infection may be controlled by therapeutic application of the same agent.

Inoculations with perfringens vaccine were not encouraging for curative or immunizing purposes, in the experience of Sir Anthony Bowlby. The use of this vaccine is advocated by some other observers in the early stages of gas infection.

Metastatic gangrenous lesions, in areas remote from the site of the traumatism, may cause death in spite of a favorable course taken by the primary focus. Patients with wounds inflicted by the B. perfringens should not be allowed to remain in a fixed position in their beds in order to guard against the danger of metastatic gangrene at the site of continued pressure. In all cases of wound infection with the B. perfringens the entire body should be carefully examined, instead of restricting attention to the region of the wound exclusively.

POISON GASES IN WARFARE ("GASSING")

A number of irrespirable gases, notably chlorine and bromine, but also carbon monoxide, oxides of nitrogen, sulphurous acid fumes, and others, have been utilized as weapons in the European war. The asphyxiating vapor given off by exploding shells is known as shell gas. Drift gas is projected from long tubes and is swept along the ground by the air-current towards the lines of the enemy.

Chlorine cannot be tolerated in a concentration of the proportion of 1:10,000; bromine and its compounds are practically equally irritating to the respiratory tract. Poison gases, aside from their pernicious effect on the broncho-pulmonary apparatus, produce intense lacrymation and transitory blindness, even in extremely weak atmosphere dilutions.

Gas poisoning, from drift and shell gas, burns the mucous lining of the respiratory passage and causes an exudation of lymph into the lungs. The victim's mouth, nose and eyes water, and he resembles a drowning man in his struggles for breath. Like other asphyxiating agents, these poisonous gases, when inhaled, cause cyanosis, an irritative cough, frothy expectoration, more or less asphyxia, and sometimes a state of collapse. These symptoms mark the first stage of gas poisoning, and gradually subside in the course of about thirty-six hours, in the majority of the cases. The "gassed" and exhausted patient usually falls into a troubled sleep.

The second stage of gas poisoning is marked by the onset of bronchitis, of variable degree; sometimes extremely rapid pulse and hurried respiration. Renal complications have been noted in form of nephritis, which is usually referred to the prolonged asphyxiation. Death is not uncommon, for gas poisoning, although it aims merely at the production of transitory irritation and disablement, often has a fatal outcome. The early symptoms in these cases are often mild and not alarm-

ing, but the "gassed" soldier suddenly dies in a state of collapse.

The inhalation of the bromine and chlorine gases used in the German army very promptly incapacitates the gassed soldiers. The chief effect of these fumes is based upon the intense reaction of the mucous membranes of the respiratory tract and conjunctivæ, resembling the effect of burns. The soldiers reach the relief stations with distressing air hunger, about forty respirations per minute; severe cyanosis; a hacking cough with watery expectorations. The temperature is abnormally low. At the end of 24 to 36 hours the exhausted patient falls asleep, to be promptly attacked by severe bronchitis with a high temperature, often terminating in death.

Bromine vapors are heavier than chlorine vapors and equally dangerous in their effects. Even in a dilution of 1 part in several millions of air, bromine vapors exert such an irritative effect upon the conjunctivæ that clear vision is prevented by the resulting lacrymation.

Investigations in German laboratories prior to the war had shown chlorine and bromine gas to be harmful even in extremely weak dilutions, owing to their highly irritative effect upon the mucous membranes. It was also found that these poison gases can be very cheaply produced in enormous quantities and that they can be easily compressed in metal cylinders for convenient transportation. For the manipulating crew, they can be rendered harmless by the use of suitable respirators and protective appliances. In order to obtain a layer of chlorine vapor 10 feet high in a dilution of 1:10,000 to act for ten minutes, with a wind of a velocity of four miles per hour, 1,000 cubic feet of pure chlorine gas are required for one hundred meters front.

The liberation of enormous amounts of carbon monoxide and nitric oxid gas, incidental to the explosion of niter compounds and the firing of large guns on

battlefield or sea, is responsible only to a limited extent for gas poisoning in warfare, owing to the powers of diffusion of the atmosphere.

Symptoms of "Gassing."—As described by soldiers who have been exposed to bromine and chlorine vapors, the first effect is irritation of the eyes, the interior of the nose and throat, causing incessant cough and severe pain in the throat and trachea. This is followed by a burning sensation, with constriction of the thorax, respiratory disturbances, and a feeling of oppression. The cough progressively becomes worse and more distressing, with profuse expectoration, stained in most cases by more or less admixture of blood. The gassed soldiers are confused and abnormally tired; some are unable to make their escape from the heavy trailing fumes and die vomiting large amounts of blood; others drag themselves to safety, strangling and spitting blood. On reaching the hospital, the men as a rule look tired out and exhausted, their eyes water, the lids are swollen, sometimes there is evidence of conjunctivitis. The cheek bones and ears are discolored and purplish, the lips are blue, the facial expression is pinched and drawn. Symptoms of dyspnea and asphyxia are present, and complaints of stitches in the side are often heard. The racking cough brings up a profuse pinkish frothy sputum, sometimes distinctly bloody. The urine is likewise blood-stained. Speech is painful and halting. The clinical picture is completed by mental confusion, with prostration and general weakness.

Although broncho-pulmonary symptoms are the most common in these cases, they are not the only manifestations of "gassing." An irritative effect of the noxious gases on the liver or the kidneys is sometimes noted, and may dominate the clinical picture. Icterus with urobilinuria is not uncommon, usually in combination with broncho-pulmonary symptoms. The course of the lesions in the bronchi and lungs, as shown by the histological and bacteriological examination of the

sputum, is characterized by the presence of desquamated elements and a few polynuclears; promptly followed by the signs of pulmonary congestion and sometimes necrosis of the lung.

The microbic flora was usually found to be irrelevant, but it is noteworthy that in a certain number of cases the sputa contained anaerobes, especially the Bacillus perfringens. In the cases of pulmonary gangrene, the microbic flora was very rich in anaerobes.

The autopsy findings in a fatal case showed the general signs of poisoning by irritative gases, in form of congestion of the entire respiratory apparatus, abnormal congestion of the digestive apparatus, degenerative changes in the liver, spleen, and kidneys; besides lesions of general pneumonia of the right lung with partial gangrene at the base. (Bull. de l'Acad. de Méd., 1915, p. 574.) The majority of the body organs are seriously damaged by the action of poison gases, not excepting the brain, which is covered with a thick layer of œdema.

As pointed out by Dr. Leonard Hill, Director Department of Applied Physiology and Hygiene, Medical Research Committtee, in his address on gas poisoning (Brit. Med. Jrl., II, 1915, p. 801), the chlorine poisoning of the lungs is comparable to extensive burns of the skin, and the same general treatment to support strength and lessen shock is required. Just as septic infection of the skin is the sequel of the burn, so pneumonia and bronchitis follow chlorine poisoning.

The symptoms of gas poisoning may be divided into symptoms of shock and symptoms of collapse, depending upon the duration of the exposure to the fumes and the strength of the heart. In the stage of gas shock, the heart still does its work, whereas in gas collapse the heart is already exhausted. The examination of gassed soldiers in the stage of gas shock shows pallor or slight cyanotic discoloration of the skin, contracted pupils, a hard but regular pulse, palpitation of the heart, more or

less impairment of consciousness, very severe asphyxia, and marked restlessness. This condition persists for a variable length of time, depending upon the strength of the heart. Some "gassed" soldiers suffer an immediate collapse. The overtaxed heart is unable to do its work, and general congestion results, manifesting itself in form of cyanosis, dyspnea, mental confusion, culminating in pulmonary œdema and death. Acting through the lungs, the poisonous war gases by way of the autonomous nerves in the bronchial mucosa exert a reflex effect upon the medulla oblongata, perhaps also irritating the motor center.

The treatment is symptomatic, and aims primarily at relieving the spasm of the smooth muscles. The spastic and contracted vessels must be dilated, and the spasm of the bronchials must be relaxed, in order to assist the heart and promote the circulation of the blood through the lungs. At the same time, this helps to expel from the lungs the still unabsorbed gas which may be present. The chief remedy in gas poisoning is atropin, but this often proves inadequate.

General Treatment of War Gas Poisoning.—Empty the air passages—as in drowning—of the contained gas, through rhythmic compression of the thorax, and institute artificial respiration. A pulmotor should be used on unconscious patients, in combination with compression of the thorax and inversion of the body. Rhythmic traction of the tongue should not be neglected. Emetics are useful in the milder cases for the cleansing out of the respiratory passages. Stimulants, such as spasthein or strychnin, are indicated as cardiac prophylactics, avoiding all vasoconstrictor agents in gas shock as distinguished from gas collapse. Instead of caffein and adrenalin, the use of camphorated ether, strophanthin, or digalen is recommended. Opinions differ concerning the value of morphin in these cases, on account of its depressing action on the respiratory center. Oxygen inhalations are inefficient as long as the pulmonary cir-

culation is impeded by vascular constriction and alveolar pressure. Subcutaneous injections of oxygen were helpful for the control of genosis and dyspnea in some cases. A useful prescription in the treatment of gas shock is as follows:

> Sulfate of atropin, 0.001 subcutaneously, repeating the injection after twelve hours, if necessary.

Treatment of Gas Collapse.—The heart of collapsed patients must be stimulated and supported, and the dilated and paralyzed peripheral vessels must be constricted. Caffein and adrenalin are therefore indicated, caffein because it directly stimulates the heart, and adrenalin because it constricts the peripheral blood vessels. Hourly injections of 0.2 to 0.3 may be administered, or 0.5 to 1.0 adrenalin (1:1000). Hot drinks, especially black coffee, are recommended. The low body temperature in gas collapse should be raised by means of hot baths, hot bricks, and similar contrivances. Cutaneous stimulation, artificial respiration, cardiac massage, all have their uses.

Local Treatment with Internal Oily Applications.—Chlorin gases are not only toxic, but above all caustic agents, and the lesions caused by them in the respiratory mucosa, from the nasal fossæ to the last bronchial ramifications, are equivalent to burns. The immediate treatment should therefore be local, and Rumpelmayer (Bulletin de l'Acad. de Méd., LXXVII, 6 Nov. 1917, p. 500) recommends topical dressings of these burns with weak gomenol oil (5 per cent.), which has first been sterilized. Intratracheal injections of this oil can be easily applied even in poorly equipped first-aid stations, by means of a long curved cannula, which in emergency cases may be introduced through the mouth without the assistance of the laryngoscope.

This early local treatment of gas poisoning was found to be both efficient and harmless. It constitutes

the rational therapy of the primary lesion and relieves the principal symptom, namely, the pain. By its analgesic and antiseptic action it affords a protection against most of the remote complications, which are due to the caustic rather than the toxic action of the poison gas. The immediate employment of internal oily dressing is looked for to save the lives of many "gassed" soldiers.

Venesection in Chlorine Gas Poisoning.—This new line of treatment was adopted by A. Stuart Hebblethwaite (Brit. Med. Jrl., II, 1916, p. 107) in selected cases of gas poisoning, namely, in deeply cyanosed patients, with severe dyspnea with a strong pulse. (Pallid collapsed patients require no bleeding, but cardiac stimulants.) In the cyanotic type, the heart is progressively weakened from overstrain in working against an increased pressure through the pulmonary system due to the inflammatory condition of the alveoli. Early venesection is accordingly needed, in order that the resistance may be lowered and thus lessen the work of the heart.

Method.—Direct incision into median cephalic or medium basilic vein, or dissection with ligature of proximal end and then incision into vein. The amount of blood extracted depends upon the patient; from plethoric and alcoholic men 20 to 25 oz., from less robust or elderly men, 15 to 20 oz. The time taken to extract 20 oz. is from fifteen to twenty minutes, because symptoms of collapse are produced if the depletion is quicker. The blood in all cases is dark and easily coagulates; in no case was there any odor of chlorin given off from the extracted blood.

In practice the following results are obtained: (1) relief of cyanosis (great); (2) relief of congestion in the lungs, enabling the patients to breathe more easily; (3) relief of the acute headache to which patients are subject after twenty-four hours of the gas poisoning; (4) promotion of sleep by the physical withdrawal of

blood from the system; a patient wakes refreshed and less distressed than before.

General bloodletting has been used very successfully in gassed soldiers of the Italian army.

After the immediate danger of gas asphyxia is over, counter-irritants are advantageously employed, especially cold moist packs of the thorax. A milk diet should be maintained as long as the fever persists. In delayed convalescence, arsenic indication in form of subcutaneous injections of sodium carodylate, is recommended by Rothberg and Michel (Paris Médical, 16 Oct. 1915, p. 389).

Remote sequelæ occasionally follow gas poisoning, in form of attacks of asthma, tachycardia, neuritis, notably sciatica; more frequently vague pains and general lassitude, which has been observed up to three months after exposure to chlorine gas vapors. Remote thyroid complications have also been mentioned. Cases have been reported in which the asphyxiating gas had apparently penetrated directly into the digestive tract, causing gastroentiritis and choleystitis, followed by intestinal gangrene, peritonitis, and death within 48 hours. Remote digestive disturbances may therefore be included among the possible sequelæ of gas poisoning.

Prevention of Gas Poisoning. — Neutralization of chlorin vapors is best obtained by means of alkalis, such as sodium salts, especially the hyposulfite and the carbonate. Masks impregnated with these substances have therefore been devised as protective appliances, all based on the principle of covering the nose and mouth with a layer of absorbent cotton impregnated with a solution of sodium hyposulfite. Sodium carbonate, ordinary water, or a very weak solution of ammonia, although less desirable, especially the latter, may be used instead of sodium hyposulfite as neutralizers of chlorine vapors. The simplest protector is made by sewing the prepared absorbent cotton in a gauze bag provided with two strings which are tied

at the back of the neck. The eyes are efficiently protected by well-fitting automobile "goggles."

Transitory or permanent neurological symptoms sometimes occur after exposure to the shell and drift gases generated by the bursting and mechanical action of explosives. In the early days of the war, prophylactic oxygen helmets and masks were suggested for the prevention of war gas poisoning and the resulting disablement, but are now apparently discarded on account of their unwieldiness.

MODERN TREATMENT OF BURNS

The modern treatment of burns, more particularly war burns, is essentially a paraffin therapy, and was introduced by Dr. Barthe de Sandfort. His "secret" preparation, known as ambrine, is a smoky-appearing odorless substance, which consists of paraffin with an addition of succinite (oleum succini), or oil of amber, and belongs to the Ambrine Company in Paris, France. Investigations conducted in the Chemical Laboratory of the American Medical Association, and published by P. N. Leech in the Journal of May 19, 1917, p. 1497, have shown ambrine to be essentially paraffin, in which a small amount of fatty and asphalt-like body is incorporated. Its composition varies somewhat, like that of most secret mixtures, but is essentially as follows:

Composition of Ambrine

Paraffin (melting-point, 48.6° C.)	97.0	per	cent.
Fatty Oil (Sesame?)	1.5	"	"
Asphalt-like Body	0.5	"	"
Coloring Matter, and undetermined	1.0	"	"
	100.0	"	"

Equivalent preparations have been offered, notably Major Hull's Paraffin Seven, the formula of which will

follow. The results obtained by him and others from the use of Paraffin Seven in war burns have surpassed those achieved by ambrine or any other tried preparation. Recent findings suggest that for most purposes simple paraffin will serve just as well as the mixtures. Simple paraffin and paraffin with various admixtures have been shown to be chemically undistinguishable. The essential point is the formation of a solid protecting film over the burned surfaces; shielding the burn from the air, and safeguarding the newly formed granulations. The favorable results of paraffin therapy are evidently due to mechanical causes.

Application of Ambrine.—Wash the burns with sterile water, and after drying paint or spray the surface with a layer of ambrine; place a thin layer of cotton wool over the parts and then apply a second coat of ambrine. On application to the skin, the preparation immediately solidifies into a tough tissue-paper-like film.

Fig. 113.—Ambrine Spray.

In the application of ambrine with a spray—as preferred by the originator of the method—the paraffin must be at a temperature of about 50° C. (122° F.). The illustration (Fig. 113) shows the metal spray pro-

ducer in use in the British Navy Medical Service. A small slab of the ambrine is put into the apparatus and heated, either over a spirit lamp or in a water bath, up to the temperature where the ambrine melts. The bellows of the spray producer are then adjusted, and the liquid wax is pumped as a very fine spray onto the burnt surface, which has been previously dried thoroughly. A cake of wax forms over the surface, and is both air tight and, from the heat at which it is applied, aseptic. A thin layer of cotton wool is then laid on this wax, and the whole is again covered with the liquid wax applied by a brush. The results, according to Hill and Penfold (Brit. Med. Jrl., I, 1917, p. 439), are very satisfactory; pain is certainly relieved rapidly, and subsequent dressings are almost painless.

Note by an American Editor.—In the experience of Dr. Rudolph Mates at the Charity Hospital and Touro Clinics in New Orleans, a cotton mop and a brush efficiently replaced the spray.

Formula for No. Seven Paraffin (Hull)

Resorcin	1	per cent.
Eucalyptus oil	2	" "
Olive oil	5	" "
Paraffin molle	25	" "
Paraffin durum	67	" "

Melt the paraffin durum and add paraffin molle and olive oil. Dissolve the resorcin in absolute alcohol (soluble in 2.1) add the alcoholic resorcin, and lastly add the eucalyptus oil when the wax has cooled to about 55° C. A paraffin containing less resorcin (0.25 per cent.) has been used with good results.

"Difficulty having been experienced in obtaining resorcin in large quantity, betanaphthol which has the additional advantage of being a cheaper antiseptic, has been substituted for resorcin in more recent prepara-

tions, as follows:" (Hull, British Med. Jour., i, 1917, p. 37.)

Beta Naphthol	0.25	per cent.
Eucalyptus	2.0	" "
Olive Oil	5.0	" "
Paraffin Molle	25.0	" "
Paraffin Durum	67.75	" "

Method of Treatment.—(The paraffin treatment is begun at the first dressing; very exceptionally, in very septic burns, the paraffin is replaced by hot boric fomentations for two days after two days of paraffin treatment.) The burn is washed with sterile water, and dried, by placing a dry piece of gauze over the burn. Next, the burn is covered with a layer of paraffin at a temperature of 50° C. Paraffin Seven has a melting-point of 48° C. In Hull's experience, a broad camel-hair brush, sterilized in wax, proved a rapid and painless method of applying the paraffin. A thin layer of absorbent cotton, cut the same size as the area of the burn, is placed over the wound after the first layer of paraffin has been applied. This layer of cotton is covered with a second layer of paraffin. The cotton is cut in thin sheets and pressed between layers of paper in order to obtain thin layers of cotton. The dressing is completed by applying cotton wool and bandage. The burns are usually dressed daily. In the later stages, when the burn is clean and only a small amount of pus is formed, the dressing is changed every 48 hours.

"Sloughs are not interfered with in any way at the first dressing; the paraffin is applied after washing the burn. At the second dressing, the dead layers of skin are cut away. Sloughs usually separate after a few dressings. The separation of sloughs is accelerated by applying a layer of jaconet over the cotton and paraffin beneath the cotton and bandage dressing."

In the New Orleans Charity Hospital and Touro Infirmary, Hull's formula No. 7, modified by substitut-

ing B. naphthol for resorcin, was used with very satisfactory results, as shown by the following quotations from Dr. Matas:

"Mr. Walker, pharmacist at the Charity Hospital, supplies the preparation at a cost of less than 18 cents per pound, and a like estimate is made by Dr. Lobenhoffer at the Touro. The mixture, when melted, is of a light yellow amber color and emits a very agreeable aromatic odor, in which the eucalyptus predominates. This odor remains after the dressing is applied for many hours, causing a very agreeable contrast with the emanation that is exhaled by the severely burned patients under the ordinary moist or dry dressings. In the application of the mixture, the general instructions given by de Sandfort and Hull have been closely followed. Gentle mopping of the secreting surface with sterile gauze and exposure to the air are sufficient preparation for the melted compound. This is applied in the liquid state at an agreeable temperature of 100° F. or less, with an absorbent cotton mop held in a long uterine forceps. The melted paraffin cools and hardens quickly as it is spread gently over the surface. When the second layer is applied over a thin cotton film, a large painter's brush is a better agent for the even distribution of the liquid; but the cotton mop is always preferable for spreading the mixture directly over the burned surface. Our experience has shown that with a cotton mop and a brush the spray is unnecessary. Burns in the more moveable regions should be covered with several layers of cotton in order to insure greater immobility and rest.

"The soothing effect of the mixture and the immediate cessation of pain in all our cases, representing every type of burn, has been perhaps the most notable and gratifying feature of the treatment. All pain ceases after the burned and blistered surfaces are covered with the paraffin, and relief continues as long as the wax is kept in place. The wax is removed with

the greatest care, as it is lifted up in large scales and sheets. In septic and suppurating conditions, the dressings should be changed at least once daily, or whenever the secretions tend to accumulate to any extent under the wax-like shield or 'carapace.' In deep burns of third degree, with extensive sloughing, the sloughs appear to be detached under the protection of this dressing with greater rapidity and less pain than by any other process; epidermization progresses more rapidly under this wax than under any other dressings that we have ever tried. Blistered surfaces and superficial sloughs which do not extend beyond the corium heal with a perfectly smooth surface, leaving no appreciable scar."

Formula for Asphalt Paraffin No. 21

Paraffin (M. P. by U. S. P. method, 47.2° C.)	97.5 gm.
Asphalt	from 3 to 5 drops
Olive Oil	1.5 c.c.

About 10 c.c. of "asphalt varnish" is placed in a beaker and heated on the steam bath for one-half hour. From three to five drops, delivered from a 1 c.c. pipet, are then placed in a casserole, and 1.5 c.c. of olive oil added. The mixture is heated and stirred for a few minutes until perfect solution is effected. To this is then added, with stirring, the paraffin, which has been previously melted. When it is cooled, a brown solid is obtained (while needless, a color resembling ambrine may be obtained by the addition of coloring agents).

The physical factors of this paraffin mixture are: melting-point, 45.4° C. (U. S. P. method); plasticity, 28.5; ductility, 29. It is very pliable and strong at 38° C., and adheres exceedingly well to the skin, although it detaches easily. This mixture, which is easy to prepare, is inexpensive, the cost of the materials being approximately 10 cents a pound. (P. N. Leech,

Chemical Laboratory of the Am. Med. Assoc. Jrl. A. M. A., May 19, 1917, p. 1497.)

Formula for Substitute Ambrine

Oil of Eucalyptus	1 part
Olive Oil	5 parts
Hard Paraffin	20 to 30 parts
Soft Paraffn	Balance to 100

This simple prescription can be put up by any druggist and be applied with an ordinary atomizer or sprayer.

A number of simple formulas for the compounding of paraffin films, each containing at most two constituents and without addition of any deodorant, antiseptic, coloring matter, etc., were suggested by Dr. Sollmann, in the Journal of the American Medical Association, April 7, 1917, p. 1037. In a later contribution (*Ibid.*, June 16, 1917, p. 1799) the application of liquid petrolatum, with a cotton swab or an ordinary oil atomizer, is recommended instead of melted paraffin for the first coat, as less painful to the patient. The cotton film is laid on the liquid petrolatum, then the melted paraffin is painted over the cotton, in the customary way. Further improvements may be attempted, according to Sollmann, by the addition of antiseptics, stimulants, and especially anæsthetics, to the liquid petrolatum of the first coat.

Opinions differ somewhat as to the behavior of the scar-tissue and ultimate complications of wounds treated with paraffin-therapy. In the extensive experience of Beiter, with treatment of burns in industrial works (Jrl. Am. Med. Ass., June 16, 1917, p. 1801), deep burns did not repair more rapidly under this method than any other, and nephritis was quite as common. Flexibility of the scars, and absence of severe contractions, have been emphasized by others, notably Sir Anthony Bowlby.

An inestimable advantage of the paraffin method, aside from its simplicity and cheapness, is the relief it brings to the agonizing pain of all burns, which renders these injuries particularly appealing. Undoubtedly, the paraffin method of treating burns has brought surcease from pain to many victims of the ghastly wounds incident to the European war, and it is welcome news that Hull's Paraffin Seven has successfully healed war burns due to cordite, petrol, and liquid fire.

Liquid Paraffin.—The use of pastes made with liquid paraffin as a base has been found to exert, in practically all cases, a very beneficial action on the walls of a wound and its surroundings. Gauze used for packing a wound smeared with a paraffin paste should be wrung out of liquid paraffin or iodoform paraffin (1 per cent.) and the skin around the wound covered with similarly impregnated gauze. In the experience of English army surgeons, wounds were successfully sutured at a very early stage after treatment by such methods.

Picric Acid.—Lotions of picric acid, in 1 to 5 per cent. solution, are advocated by a number of clinicians, on account of their analgesic and healing properties, as well as their inhibitory effect on bacterial growth. The first dressing need not be changed for forty-eight hours; it can be sterilized, and will absorb all discharges. When applied immediately after burns, picric acid serves to prevent the formation of vesicles. The remedy causes a yellowish discoloration of the skin, which persists a long time. Poisoning through absorption is a very remote risk, provided weak dilutions are used and the burns do not involve a very extensive body surface. No symptoms of poisoning were observed by Dr. E. H. Risley in all burned cases receiving this treatment at the Massachusetts General Hospital for a period of one year from May, 1914. "In first-degree burns it leaves a clean, dry and probably sterile surface and relieves pain very quickly. In second-degree cases it has proven a splendid dressing, leaving in a few days a dry sur-

face, all discharge being readily absorbed through the dressing, and an area which practically never becomes septic and heals quickly."

Chloride of Iron.—On the basis of personal experience in the last six months with a series of cases in which first and second degree burns of limited extent were treated with tincture of iron chloride, Risley considers this method satisfactory in superficial and not too extensive burns. No dressing is required. The tincture is simply sopped on over the burned area; repeated applications should be made once an hour or so until a dry protective layer is formed; after this, only occasional applications need be made. The area is best left uncovered, as a thorough drying is what is desired.

The prevention of shock, sepsis, toxic complications such as nephritis and duodenal ulcer, and contractures due to burns, is not considered in this brief presentation of the modern treatment of burns. But mention must be made of the fact that sepsis can be prevented, in the experience of Dr. Risley, by the open-air treatment and the salt solution compress, cleansing of the surrounding skin, and avoidance of oily dressings at the onset.

CHAPTER VII

SOME MEDICO-LEGAL CONSIDERATIONS

The lesions studied in this book have in the majority of cases been such as to render necessary either the patient's final discharge from the army, or at least a very prolonged period of convalescence, or his reclassification into some other branch of the service. In this connection there arise medico-legal questions exactly similar to those that have to be decided in our expert medical evidence in connection with the accidents of civil life; questions that are often most complex, concerning which military law has not so far been very definite, and in which it will prove useful to compare the military rules with the results of arbitration in civil cases.

I. Methods of Disposal of the Wounded after Cure

When a patient has been cured of his wounds, the chief medical officer of the hospital has to decide definitely whether :—

In cases where he considers that the patient will on the expiry of his leave be fit to rejoin his depot and finally proceed to the front, to grant the usual period of seven days' sick furlough.

Or, in cases where he considers one of the following courses necessary, to send the patient to a hospital depot where sits a special medical board :—

(1) The patient is fit to remain in the actual fighting forces, but possesses a special partial disability which will necessitate

(*a*) his employment on some special duty with his unit,
(*b*) his reclassification into some other branch of the combatant forces.

(2) The patient is unfit for a combatant unit, but fit for duty in one of the auxiliary services.

(3) The patient is unfit for any service, and should be proposed for

(*a*) discharge with a pension where his incapacity is 60 per cent. or over,
(*b*) discharge with or without a gratuity where his incapacity is below 60 per cent.

(4) It is impossible as yet to classify the patient into one of these categories : time is necessary to ascertain what his final condition is going to be. In such cases there will be proposed, according to the period anticipated as necessary,

(*a*) a period of convalescent furlough,
(*b*) a temporary discharge from the army.

In practice, according to the *Regulations of the Army Medical Service of the Interior* (8th edition, April 1914, p. 252 and following), such suggestions for disposal of the patient must be entered on his medical examination certificate by the medical officer in charge of the case or of the hospital in which the wounded man

has been treated. In actual war, however, medical officers have for the most part contented themselves with indicating and assigning the patients to these classes on the clinical history sheet on which they describe the condition of the patient on his discharge from hospital; they should, however (and several circulars have been sent round calling attention to this), fill in the form dealing with pensions and gratuities.

In cases where it is proposed to transfer the patient to some other branch of the combatant service, or into one of the auxiliary services, or to grant convalescent leave, it is necessary to take into consideration very many different factors; these have been specified in special circulars, as they could not be all enumerated in the regulations. Special care and judgment is necessary in each individual case to determine, for example, that a man obviously unfit, at any rate for some considerable time, to carry a pack because of the presence of a scar on his back, is nevertheless able to fulfil certain other duties of the infantryman; that a man quite unfitted for marching because of a scar adherent to his tibia that has been involved in the inflammation, may be useful in the artillery, cavalry, air services, or in a munition factory.

All this depends at once on the present certified state of the lesion, on the nature of the corresponding functional disability, on the patient's previous occupation, on his special physical and mental capabilities. It has been laid down as a general rule—I shall return later to a discussion of this point—that in estimating the percentage of incapacity, the expert should pay no attention to the previous occupation of the patient

(*Regulations*, p. 276, X); but I hold that he should take it into consideration and regard it as important, especially in distinguishing men likely to be useful in the combatant or in the auxiliary services.

Such being the general principles, some remarks as regards special points will perhaps be useful.

II. When should the Patient be regarded as Cured ?

As regard convalescent leave and temporary discharge, it was not long before practical difficulties arose, especially in cases of peripheral nerve lesions—with which we are not concerned here—and of chronic osteomyelitis, such as we have been occupied with in this book.

At what moment can one say that the lesion justifies one of these proposals ?

Until recently the general instructions seemed to be to keep all patients with chronic sinuses in hospital until a complete cure was obtained, *i.e.* until the wound had completely healed.

But a little knowledge and experience of osteomyelitis serves to show that complete healing of the lesion often takes a very long time, that it often entails delays which cannot be foreseen, during which a small sinus persists, requiring occasional dressing and resulting in the discharge sometimes daily, sometimes only occasionally, of a few drops of pus. We know also that complete healing is not necessarily final, that late formation, even after months or years of apparent cure, of sinuses and even of actual abscesses, is not at all a rare occurrence.

In cases where clinical and radiographic examination show the existence of sequestra, or of a focus of

caries, or of a cavity in the bone with overhanging walls, the performance of an adequate operation should not be delayed.

If none of these conditions exist, that is to say, if there be no indication for operation, the patient should be discharged if in addition to the sinus there be present a lesion that definitely renders him unfit for service; convalescent leave should be granted in cases in which this second condition is not fulfilled.

This condition depends on the functional state of the limb, the presence of shortening, of mal-union of the fracture, and upon the amount of free movement in and the position of the neighbouring joints. The expert should then judge whether or not such a state justifies transference to one of the auxiliary services, whether reclassification in the combatant services or temporary or final discharge best fits the case.

In cases of persistent sinus due to osteitis of the shaft of a long bone, this by itself is not sufficient justification for definite discharge; prolonged convalescence under the supervision of a surgeon with experience of the surgery of bone lesions would be a suitable method of disposal.

For months I maintained this opinion without being successful in bringing about a change. At the convalescent depots the smallest crust used to be scraped off, and if under it was found a point of bleeding granulation the case was sent back to hospital as insufficiently cured.

For some time now, thanks to the very precise instructions of the inspecting director of medical services of Paris, sound surgical teaching has triumphed.

Where an operation is indicated (and it is well for the advice of a surgeon of reputation to be obtained) it should be performed as soon as possible.

Where no operation is indicated, no time should be lost in adopting one or other of the courses enumerated above, so that hospitals may not be uselessly encumbered with wounded who are able to work, getting their sinuses dressed once or twice a week at the military hospital nearest to their place of residence. They can be admitted again to hospital if a return of the inflammation necessitates any further surgical treatment.

This is how in the past we have been accustomed to treat all our civil cases of osteomyelitis; there is no reason for refusing to use this method in military cases: except in a few cases—and in these retention in hospital is of course the patient's due—this is what the patient himself desires above all things; it is much more economic to the State, and much more favourable to the recuperation of the patient.

I do not know whether or not such a method is employed in all the military districts of the interior; it seems to me that it should be in general use, and that is why I describe here what is actually in operation in Paris.

III. Pensions and Gratuities

According to the *Regulations of the Medical Service of the Army of the Interior* (vol. lxxx., 6th edition, issued up to the 1st April 1914), diseases and disabilities attributable to military services are of two varieties :—

(1) Those whose severity justifies discharge from the army with a pension ;[1] an official list of these is recounted.

(2) Those which, resulting in a disability or incapacity of a less severe nature—not found or mentioned in the above official list—justify discharge No. 1 with a gratuity, that may if necessary be repeated.

At once medical men noticed a very singular detail in these regulations : only certificates for discharge with a pension should mention the incurability of the lesion ; certificates for discharge No. 1 " must never certify incurability."

This conception of incurability has doubtless been the cause of many of the curious criticisms directed against the " Table of classification of wounds entitling patients to a pension in accordance with the various categories fixed by the Laws of the 11th and 18th April 1831."

Thus to have made use of the numbers of the old classification in connection with the medicine and surgery of 1914, the unfortunate but anonymous persons responsible for these regulations must have been still under the influence of the state of medical and surgical knowledge in 1831.

They must have been influenced too by the administrative necessity of not submitting to the alternative of the " renewable gratuity " in cases of discharge No. 1. For example, we find classed together into

[1] The Law of 1831 was concerned with the loss of a limb or some similar incapacity. A little after the commencement of the present war supplementary instructions specified that a pension—the original difference between this and gratuity has been maintained—was to be granted in all cases in which the disability resulted in a loss of at least 60 per cent. of the functional capacity. Hence the publication of a *Handbook of Guidance and Reference* that I shall deal with later, and which all civil experts would do well to procure.

the sixth and last category, amputation of the great toe with its metatarsal bone, of two toes with their metatarsal bones, that of the five toes, ankylosis of the knee, elbow, and hip joints in good position, and ankylosis of the shoulder. The incapacity is regarded as identical in the case of amputation of the thumb with or without its metacarpal bone—a point I certainly consider as contestable. And is it at all reasonable to establish even in the sixth category an identity of incapacity between these lesions and that due to the "loss of function of a limb" merely in order to keep within the classification of the Law of 1831?

All this results in untruthful and quite inadmissible assertions, for in the certificate of incurability in the case of discharge with a pension the medical officer has (p. 261 of the *Regulations*) to declare that the lesion is grave and incurable, and that it renders the patient not only unfit for service, but also unfit to earn his living.

And I have seen certificates in which medical men have not hesitated, merely to keep within the regulations, to certify that ankylosis of the elbow or shoulder makes a man unfit to earn his living. Take this nomenclature and see in how many cases it is in accordance with established facts—in but very few—and I may add, that in accordance with its provisions a larger pension goes to those with amputation of the thigh (third class) than to hemiplegic lunatics, to those suffering from general paralysis in the stage of incontinence (fourth class), or even in the stage of imbecility (fifth class).

Let us now pass on and leave these defects in classification; as a matter of fact, in the early days of the war the instructions relative to pensions and discharges

were very badly drafted, and those responsible for them seem to have been very largely out of touch with the knowledge and experience gained by expert medical witnesses since the passing of the Workmen's Compensation Acts ; and what real difference is there between the two sets of cases, civil and military ?

And especially when one considered the appalling number of the disabled did the necessity appear absolute for the authorities to provide medical officers with a set of instructions at once more precise and up to date ; hence the order of 24th March 1915, and the appearance of a *Handbook of Guidance and Reference*, whose author, although anonymous, has certainly proved himself very competent.

This Handbook besides pretends to be no more than a guide, for the author holds that the after-results of accidents—even the accidents of warfare—are quite incapable of classification into any absolute scheme, no matter how comprehensive or exhaustive. There are of course certain typical cases in which the incapacity, always identical, can be estimated, so to speak, almost automatically ; but in nearly all cases an accurate estimation of the degree of incapacity is possible only by an expert clinical examination that perforce has to take into account a great many factors of the utmost variability in different cases.

The object of this little book is primarily to establish different classes of gratuities corresponding to percentages of functional incapacity to compensate for those lesions that are not from the outset sufficiently serious and disabling to justify the patient's discharge on a permanent pension ; those valuations of gratuity are based on the awards of the civil courts in cases of compensation for the accidents of employees.

Instead of following too closely, however, the example of civil arbitration—in which the incapacity for work is estimated at the moment of the examination and report, but remains liable to revision for better or for worse for a period of three years—the military authorities have retained their original division of methods of compensation into pensions and gratuities.

For cases of incurable incapacity amounting to less than 60 per cent. a new class of permanent gratuities has been established; the reason for this further class in addition to pensions is not altogether clear; what matters is the permanence and not the percentage of the incapacity.

For cases of incapacity liable to undergo in time a change of extent or severity the original temporary gratuity has been retained. It is obvious that this is right, because with our usual electoral methods procedures of revision properly so called would only give rise to difficulties that can be easily foreseen.

The writer of this Handbook takes care to declare in the most absolute manner that his work is not intended "In the very least to modify the scale of gravity of wounds or of incapacity decided on by the administrative authorities of 23rd July 1887, and expounded in the Instructions of 23rd July 1887 and of 23rd March 1897." And he concludes that medical experts will continue to make use until further orders of this scale of 23rd July 1887 when dealing with such severe and incurable disabilities as warrant the patient's discharge from the army on pension." They make use of this Handbook and consult the percentages that it suggests for disabilities and illnesses incapable of being regarded as severe and incurable in all their

aspects, and so of fulfilling the conditions laid down by the Law of 11th April 1831 as alone justifying permanent discharge from the army.

The Instructions of the Handbook then, with the single exception that we have alluded to as regards the permanent gratuity, are perfectly clear and definite. But they are certainly rendered less valuable and efficient by the statement "that it is not intended in the least to modify the former scale of gravity, etc."

However, it does modify it, and it is good that it has done so in such a way as to eliminate those absurdities, to some of which I have already called attention. But the consequence of this attempt of the authorities to save appearances is that a considerable number of doctors still continue to refer to this faulty nomenclature, that many discharges continue to be described as belonging to "categories," in a typical one of which disarticulation of the shoulder, of the hip, and of the ankle joints are grouped together as of the same order of severity.

Our point of view is surely that of the author of the Handbook, since he attributes to the various amputations a different percentage of incapacity. It would, then, have been better to have cancelled completely the former scale of gravity, since all its numbers reappear in the new.

I believe also that in this new classification it was a mistake to put amputation of the upper extremity above and below the elbow joint into the same category, and also to estimate at 100 per cent. the incapacity of double amputation of the foot. Such do not take into account the functional results obtained by the expert application of artificial limbs.

In this connection I will make reference to a

principle indicated in but a few words in the Guide, but which, in my opinion, deserves a position of prominence.

It is *à propos* of amputation of the lower third of the leg that it refers to cases in which "the stump is healthy, the scar firm and in a good position."

Now this is a remark worthy not only of emphasis but of wide application. In considering the percentage of incapacity in cases of amputation, the quality of the artificial limb to be worn should be an important factor in the decision; one should consider most carefully in each case what variety of artificial limb will be suitable to such conditions as may be present, *e.g.* the particular shape and length of the stump, the position of the scars, the presence of infection of the bone, the existence of tender spots. The length, it might be said, is sufficiently indicated by the naming of the level of the amputation; this is not altogether so, especially in two cases, amputation through the surgical neck of the humerus and sub-trochanteric amputation of the femur are amputations of the arm and leg respectively, yet from the point of view of the future artificial limb they are no better than the corresponding disarticulations, for so short a stump is of but little use either for weight-bearing or for the transmission of movement to the apparatus.

This takes me on to a still more generalised observation, with which I shall end this section.

In reporting on the incapacity resulting from civil accidents we are accustomed to consider as an important element in determining the percentage the former occupation of the injured man. Amputation, for example, does not constitute so great an incapacity

in the case of an accountant as of a navvy. It is a matter for regret that such is not taken into consideration in the case of wounded soldiers about to be discharged, but one should recognise that for various reasons, sentimental, political, and otherwise, this would be difficult to systematise ; the public would not understand these differences in the case of soldiers with the same wound—equally "glorious" ; such points can be understood only by competent experts.

IV. The Refusal of Treatment

The medico-legal question that has recently attracted most attention is that of the refusal of the soldier to undergo a certain mode of treatment or to submit to a certain operation.

This question has been dealt with at great length in the political press in connection with a case that a few weeks ago ended in a court-martial. The subject being brought up by one of its members, the Academy of Medicine after quite a long discussion in a secret sitting passed a resolution that I shall quote further on.

I have taken the following account of a case as detailed in a serious daily paper in an article that aimed at being considered witty :—

A man was brought before a court-martial for refusing certain treatment just as though this was a refusal to obey orders, and the journalist made fun of the doctor for applying to a military court instead of using moral suasion and inspiring the patient with confidence.

Had the circumstances really been as stated, the journalist would certainly have been right, and no doctor would disagree with me in saying so, but

unfortunately he wrote carelessly without troubling to verify his facts, for the case was really very different: an obvious malingerer on having an electric shock administered to him suddenly found himself able to stand up and strike the major several blows with his fist: he was tried and condemned for assault on a superior officer.

This was certainly not a case of court-martial invoked by a doctor for refusal of treatment as if for disobedience of orders.

But has the doctor the right to submit a patient to any form of treatment whatsoever which the patient has not a corresponding right to refuse? Such is the conclusion that the Academy of Medicine has come to (*Bulletin*, 1916, vol. ii. p. 210) in deciding on the following "order of the day":—

"In a secret sitting the Academy has adopted the following conclusion concerning the methods of intervention and examination that may become necessary in the diagnosis and treatment of cases in the military medical service:—

"Under the conviction that all measures have been or will be taken to secure for sick and wounded soldiers the competent medical and surgical attendance and treatment to which they are entitled, the Academy, considering the question from a purely medical point of view, considers that sick and wounded soldiers are not justified in withholding their consent to any procedures of clinical investigation necessary for diagnosis, or to any methods of medical or surgical treatment that are in accord with the present state of our knowledge and experience and that are likely to result in cure."

The wording of this seems to me to be poor, for it takes no account of the fact that surgical methods of treatment, though quite in accord with the present state of our knowledge, can and do possess an element of danger, were it only that of the administration of the anæsthetic, that all surgeons are not equally skilful, and that the functional result of an operation

can be anticipated in terms of probability and not of certainty.

I much prefer the official text published in the B. O. B. P. of the 5th April 1915 under the title :—

Instruction relative to the Courses of Action necessitated by the Refusal by the Soldier of Treatment or Operation recognised as necessary

The Minister has at different times been consulted as to the course of action that should be taken in the case of soldiers on active service or of wounded in hospital who, for various reasons (an imperfect comprehension of their own true interests, wrong-headed wilfulness, or with the intention of prolonging their stay in hospitals, and sometime also in the hope of escaping military service or of obtaining a permanent or larger pension), refuse treatment or operation of such a nature as either to confer immunity against certain diseases or to result in the cure or improvement of their incapacity for work produced by wounds.

Generally speaking, one should in such cases avoid having recourse to any measure of coercion at all. The doctor should try persuasion, explaining to the soldier the object of the proposed procedure, pointing out to him his own best interests and the benefit that he will derive from the treatment or operation to which he is hesitating to submit himself.

Where the refusal, however, is absolute, the solution will vary according to the object and nature of the proposed treatment or operation :—

(1) When in connection with such procedures ordained by law to protect the health both of the individual and of the general public or army, as vaccination against smallpox and typhoid fever, such refusal is inadmissible.

Such treatment should be carried out officially in the interest of the whole army, and the refusal to submit to it treated as similar to a military crime, and justifying disciplinary measures of repression.

(2) When a wounded man refuses a simple and bloodless method of treatment, *e.g.* the different forms of physiotherapy, massage, mechanical manipulation, heat baths, electrotherapy, etc., which, while being quite free from risk are such as to lessen the disability from which he is suffering and to increase his capacity for work, he should be treated as a malingerer who intentionally keeps open or aggravates his wound by refusing treatment so as to limit or

annul his subsequent usefulness as a combatant, or of increasing either his chances or the actual amount of a future pension.

By such conduct he may incur the various disciplinary measures laid down for such misdemeanours without prejudicing the possibility of an ultimate reduction of the percentage of his incapacity for which compensation will be granted similar to that indicated in the following paragraph:—

(3) The right to refuse an open operation with or without an anæsthetic is considered as absolute by the law on account of the fact that every such operation involves a certain risk of death; but the exercise of this formal right carries with it certain responsibilities, *e.g.* exposes the patient to a possible reduction of the future amount of his compensation, especially in the two following cases:—

(*a*) When the operation is a very slight one, especially when it does not necessitate the administration of an anæsthetic, *e.g.* the incision of a superficial abscess, the removal of a quite easily accessible bullet.

(*b*) When the performance of an operation is rendered urgent and necessary beyond all manner of doubt by the occurrence of some complication that is likely to lead to some absolute or serious incapacity, *e.g.* the refusal to allow the enucleation of an injured eye where the onset of sympathetic ophthalmia is feared, the refusal to allow amputation of a gangrenous limb, etc.

In such cases it is of course the duty of the medical man, both as professional adviser and as friend, to explain to the patient that operation forms the only chance of his survival, of his prompt cure, or of diminishing his incapacity, as the case may be.

He should offer to call into consultation one or even more consultants, or finally, and if necessary, propose to transfer him to the surgical centre of the military district.

If, in spite of all this, the patient still persists in refusing, the medical officer will draw up a report which will exactly specify the nature of the operation and the condition that has rendered it necessary, as well as the refusal of the patient, with his motives in refusing. This will be signed by the patient, the doctor in charge of the case, and the officer in charge of the hospital; if the patient refuses to sign, mention of this will be made in the report.

This report will be completed in duplicate, one copy being kept by the officer in charge of the hospital, the other sent to the headquarters of the unit to which the patient belongs.

On discharge of the patient from hospital, or on his return from convalescent leave, two possible cases are to be considered:—

(1) Where the wounded man is still fit for duty as a combatant or in one of the auxiliary services, he will then return to his depot, and will be utilised in accordance with the regulations in force at

the time dealing with the standard of physical fitness until his term of service is up, and then later in the reserve.

(2) Where the wounded man, at the end of his period of service, presents a variable reduction in his capacity for work, or where, on leaving hospital or later, he is considered incapable of further service, in such cases he will be brought before a special discharging board and examined in accordance with the regulations in force, with a view to proposal for discharge with a gratuity or discharge with a pension.

In all cases, in assessing his percentage of reduction of capacity for work, the examining experts, placed in possession of the report as to his refusal of treatment or operation, will specify in the form of a fraction the proportion of such incapacity reducible by the performance of the proposed operation.

The proposals of this board will be recorded, an account being taken of the proportion of the total incapacity due to the refusal of treatment.

A committee of consultants, or, in its absence, a special medical board, will finally pass judgment from the point of view both of the seriousness and of the incurability of the disability, as to the reduction of full capacity for work due directly to the actual wound itself and that resulting from the refusal of treatment or operation.

Hence when a patient refuses treatment an official report should be filled in and signed both by the doctor, who should state the exact nature and aim of the proposed treatment, and declare it to be free from all danger, and also by the patient, who should indicate the reason for his refusal.

The final judgment has to obtain the sanction of the military authorities, but it is obvious that the considered opinion of medical experts will be of the greatest importance in determining two points :—

(1) That from such a refusal directly results a persistence of incapacity the degree of which would be reduced by the treatment.

(2) That the man is a malingerer, or at least that he fears that the treatment, operative or not, would render him fit again for active service.

In case (1), the medical report will follow the lines of

our expert evidence before civil arbitration tribunals: it is pointed out what the actual percentage of incapacity is and what it probably would be after the operation; the tribunal then judges the case in the light of this evidence, usually debiting against the workman the fact of his unwillingness.

Cases of malingering seem at first sight very simple; such may well be so in cases in which the diagnosis is certain; in these cases in the special neurological centres a skilful clinician is generally successful in proving the fraud. All that is then necessary is to fill in a report, giving full details with the proofs in support, and then to return the delinquent into the hands of the military authorities.

But it should be recognised that complicated and difficult cases occur—indeed they are not at all rare—in which the diagnosis remains uncertain, concerning which a definite opinion cannot be pronounced, at least at first.

Putting on one side cases of real traumatic hysteria characterised by contractures and paralyses—such patients are genuinely and sincerely ill, and require to be treated accordingly—and also cases of true retraction of muscles and tendons due to sclerosis, there still remain a whole group of cases of wounds involving or lying close to muscles that become complicated by the occurrence of contractures; in these it is difficult to decide whether they are reflex or assumed.

In cases in which the patient has kept professing his desire to return to the trenches—a thing the general public is far too prone to believe—my impression is, that if this desire were genuine he would soon be successful in achieving the very slight effort

of the will which is all that is necessary to bear the initial pain and to become cured. This effort he does not make, not because he is altogether a malingerer, but at any rate in part because he is really not at all anxious to be discharged from hospital. This is an example of unconscious psychology, or, to make use of the language of modern philosophy, of the psychology of the subconscious mind.

Such a state of affairs most often occurs with wounds affecting the foot. Because of some painful or tender scar, often very insignificant in itself, *e.g.* slight perforating bullet wounds somewhere near the tendo Achillis, the patient begins to walk on the outer edge of the foot. This he continues to do, and the foot becomes fixed in equino-varus by contracture of the calf muscles and the tibialis anticus. There must be in such a condition some material physical basis—so far not successfully accounted for, it is true, for I have seen such cases in which could be provoked clonic spasms like those of Jacksonian epilepsy. But in these cases nothing definite can be made out in the way of sclerosis of muscle, since under an anæsthetic, and even sometimes without an anæsthetic, by taking advantage of a moment of muscular relaxation, complete correction can be obtained without the use of the least amount of force.

But fix such a foot in plaster in the position of valgus for two to three weeks; immediately on removal of the plaster the contracture will reappear.

Is this malingering, deliberate deceit, or the result of the subconscious mentality of the neuropath who, without perhaps actually confessing it even to himself, prefers to remain where he is? It is just possible—I think it is even probable—that a tenotomy would

cure this contracture ; but our experience and knowledge of these cases is still not sufficient to warrant our insisting on this treatment.

A very similar position obtains as regards those cases of muscular contracture in which, by some special method of muscle training—in which also no doubt the will plays an important part—the patient is enabled to exhibit the phenomenon of the "snapping joint."

Such cases should not be subjected to court-martial, but are amenable to psychotherapy ; and there exist certain special centres where such psychoneuroses—often of a most difficult and complicated nature—are treated under the direction of competent specialists.

The only way of arriving at an accurate diagnosis of such patients as either refuse treatment or submit to it with a bad grace is to keep them under exact and constant surveillance.

SECTION IV

WAR OTITIS AND WAR DEAFNESS

WAR OTITIS AND WAR DEAFNESS

FIRST PART

NON-TRAUMATIC OTITIS

War Injuries are not the only lesions of the ear which require the Army doctor's care. The aural affections, whether old-standing or recent, which he is called upon to treat, are numerous. Some are compatible with combatant service, provided elementary precautions are taken; others call for treatment in hospital on account of their seriousness or the advantage of entrusting them to a specialist with a view to complete and speedy cure. For this reason we have devoted the first pages of this book to an account of the existing therapeutic indications for the principal aural affections.

CHAPTER I

EXTERNAL OTITIS

FURUNCLE

Diagnosis.—A furuncle is always situated in the external cartilaginous portion of the auditory meatus. It is visible without the use of special instruments.

It is very painful, and the intensity of the pain may lead to the illusion that the affection is of a serious nature; the insomnia, the starvation consequent upon the suffering accompanying mastication, and moderate pyrexia, alter the expression of the face to a certain extent, and favour the false impression.

A diagnosis can be arrived at after a careful examination.

Furuncles may be small and superficial, or deep-seated, the latter attaining to a considerable size.

The former present the appearance, when the auricle is pulled upwards and backwards, of pointed swellings, which, when mature, are yellowish at their summit.

The deep-seated ones appear as rounded projections, wide at their base, which more or less occlude the lumen of the meatus; they develop into sub-cutaneous abscesses; they become complicated by infiltration of the cellular tissue round the auricle. In the case of anterior furuncles, there would be œdema and redness of the tragus, lymphangitis and adenitis in front of the tragus; in the case of the posterior ones, œdema, redness, lymphangitis and adenitis in the mastoid region; in the inferior ones, parotid adenitis; in the superior, infiltration of the sub-cutaneous cellular tissue of the temporal region.

This outward extension, and particularly the swelling behind the auricle, which resembles at first sight that of mastoiditis, may lead us into error. An important sign distinguishing a furuncle is the character of the induced pain. The pain is, in fact, increased by any attempt to manipulate the meatus. If the furuncle is anterior, mastication is impossible and pressure on the tragus is unbearable; in the

case of a superior furuncle traction of the auricle upwards is painful; traction backwards in the posterior; pressure underneath and elevation of the meatus, in the inferior.

This peculiar characteristic of the induced pain renders it possible for the non-specialist to attribute the otalgia from a furuncle to its proper cause. The diagnosis is in reality only doubtful when it lies between certain posterior furuncles and mastoiditis, especially when there is at the same time suppuration in the middle ear. We have attempted to put together the chief points in the table on pages 812 and 813

Treatment.—It will be found sufficient to treat simple cases by the application of moist dressings over the region of the ear, and the instillation of soothing antiseptic drops, such as :—

Van Swieten's Liquor (Liq. Hydrarg. Perchlor.)
Neutral Glycerine, of each 20 grammes

or

Carbolic Acid Crystals	1 gramme
Neutral Glycerine	40 grammes

This method sometimes has the inconvenient result of causing maceration of the skin and of exposing it to successive inoculations.

Recurring furuncles, as well as the deep-seated ones which are characterised by lengthy development and puffiness of the regions round about the auricle, require surgical treatment at the hands of a specialist. This treatment consists of an incision at the moment of maturation; an opening made too early is useless and may be even harmful. This little operation causes intense pain, and it is advisable to anæsthetise the patient by means of the inhalation of a few whiffs

	Furuncle.	*Acute median otitis.*	*Acute median otitis* (complicated by mastoiditis).	*Acute or chronic suppurative median otitis* (complicated by furuncle).
Previous history	Furunculosis. Dry eczema with pruritus and abrasion.	Naso-pharyngeal infection.	Naso-pharyngeal infection followed by acute median otitis.	More or less old-standing otorrhœa with dermatitis.
Onset. Course	Sudden. Course—in successive attacks.	Onset, more or less sudden. Course progressive. Relief from pain on commencement of discharge.	Onset gradual. Course progressive.	As in simple furuncle.
Hearing-power	Normal, except if the meatus is occluded.	Greatly diminished.	Greatly diminished.	More or less diminished.
Discharge	Slight. Thick from the first.	Profuse. Sero-purulent, then purulent.	Sometimes very profuse; sometimes slight; always purulent.	Variable in quantity.
Peri-auricular swelling	Variable according to situation of furuncle. When behind, simulates mastoiditis.	None.	If mastoiditis extending outwards, retro-auricular swelling with displacement of auricle.	As in simple furuncle.

Induced pain	By manipulation of meatus. When there is mastoid lymphangitis, pressure on œdematous zone is painful; the neighbouring bone is not tender and manipulation of meatus is always more painful than pressure on mastoid region.	By pressure on tragus and antrum.	By pressure on the whole of the mastoid process, on the tip and posterior edge, outside the œdematous zone. Manipulation of the auricle is painless.	As in simple furuncle.
Otoscopic examination	Swelling of the external part of the auditory meatus.	Meatus clear; tympanic membrane red and bulging, subsequently perforated.	Mastoiditis may extend to the meatus with formation of a fistula, but this fistula is accompanied by swelling or sagging of the postero-superior wall of the deep bony part of the meatus. The bone can be felt with a probe. The cartilaginous meatus is normal.	There are simultaneously lesions of the external auditory meatus, the tympanic membrane and the cavity of the tympanum.

of chloride of ethyl. The incision is carried out by means of a furunculotome, or better still by the use of the galvano-cautery. It is followed by expression, then by frequently repeated dressings with small strips of gauze moistened with alcohol or Alibour water,[1] and over the dressing a square of absorbent cotton wool and a bandage. At each dressing the part should be carefully dried, as it is important to avoid maceration of the integuments.

Furuncles sometimes recur in a disheartening manner; for such cases, in time of peace, we resort to auto-vaccines according to Mauté's method.

ACUTE DIFFUSE EXTERNAL OTITIS

Diffuse external otitis is an inflammation of the cutaneous lining of the external meatus in general, spreading even to the tympanic membrane. It may follow a local inoculation or suppuration of the middle ear. In otorrhœa the skin of the external meatus becomes infected all the more readily as the repeated use of irritant antiseptics favours the penetration and development of pathogenic germs.

The clinical picture of diffuse external otitis is the same as that of furunculous otitis, but it is more exaggerated; the pain in the ear is extremely violent during mastication, which is thus rendered impossible; the slightest pressure on the tragus, the auricle, the parotid and mastoid regions gives rise to intense pain.

The meatus is completely occluded by the swelling of the infiltrated skin, which is red and covered with pus.

[1] Copper Sulphate, 2½ drachms; Zinc Sulphate, 9 drachms; Camphor, 1 drachm; Powdered Saffron, ½ drachm; Water, 40 ounces.

The œdema, the lymphangitis and the adenitis give rise to considerable swelling round the ear. High temperature is persistent and may reach 38·5° to 39° C. (101·3–102·2° F.).

The ***diagnosis*** of diffuse external otitis rests upon the intensity of the symptoms, the character of the pain peculiar to lesions of the meatus, and the spreading of the inflammation over the whole of the cutaneous lining of the meatus.

The difficulty is to locate the origin of the dermatitis. At the outset this cannot be determined. As with furunculous otitis, the acute symptoms must first be alleviated in order that a view of the meatus may be obtained; when it is possible to introduce a speculum the existence of a previous furunculosis or of median otitis will often be recognised.

For ***treatment,*** admission into a field ambulance or a special hospital is necessary. All traumatism or irritation of the integuments of the meatus must be avoided.

At first, warm moist dressings and general analgesics are employed.

After forty-eight hours of treatment a small speculum can usually be introduced. By means of Hartmann's small cannula syringing with tepid boiled water or a slightly alkaline solution is carried out; the deeper part of the meatus is thus cleared of desquamative epithelial débris which have accumulated there. Acute or chronic median otitis may or may not be present. Careful drying should be carried out and the walls of the meatus plastered with a thin layer of oily cream containing oxide of zinc.[1] A dry aseptic strip of gauze is introduced reaching to

See page 818

the tympanic membrane; this absorbs the pus as fast as it is formed. The dressing should be renewed once or oftener in twenty-four hours according to the case.

In cases infected with the Bacillus Pyocyaneus, the use of Peru balsam is recommended. After cleansing and drying, five or six drops of the pure balsam should be poured into the meatus: this treatment should be continued for six or seven days.

INDUCED EXTERNAL OTITIS

Some cases of external otitis take an abnormally long time to cure, and the symptoms return more markedly when discharge from hospital is imminent. One of the authors has seen a case of external otitis with an unusually profuse suppuration in an individual convicted of inducing conjunctivitis with ipecacuanha powder; the agent employed to cause the otitis was not discovered.

Treatment.—As soon as possible, isolation, forbidding of outings on account of the frequent dressings, strictly low diet.

The dressing should be carried out by the doctor or under his supervision; it should be thick and impervious; an endeavour should be made to find out if the patient displaces it between the sittings. The patient should be discharged from hospital without convalescent leave; on his case-paper should be written: "Simple external otitis subject to recurrences; no middle ear suppuration; no possibility of complications in the ordinary course of events, and quite compatible with combatant service."

This method has been found sufficiently prophylactic.

CHRONIC ECZEMA

Eczema of the external meatus is of frequent occurrence; it is not serious but often fairly annoying.

It may occur as a primary condition, but sometimes arises from local irritation caused by the contact of the pus from chronic suppurative median otitis.

The patient always complains of the same symptom: *violent itching at night-time;* he scratches the part and rubs the skin off; in this way furuncles frequently have their origin.

The auricle and meatus are generally affected at the same time.

In simple cases the skin is dry, cracked and scaly. The scales may be mixed with cerumen or with pus from the tympanum, forming hard plugs which cause deafness; the extraction of these by means of syringing restores the hearing.

Under the influence of certain conditions—errors of diet, neglect of cleanliness of the part—the chronic eczema is complicated by acute attacks; the skin becomes red, swollen and the purulent oozing is extremely abundant.

The *treatment* of the dry chronic form consists in clearing away the epidermised debris by one or two swabbings with nitrate of silver, 1–20. Cure may follow immediately; if not, one of the classic ointments containing tar or ichthyol may be used, such as :—

Washed crude tar		1 gramme
Ichthyol		2 grammes
Lanoline	aā	6 grammes
Oxide of zinc	aā	6 grammes
Vaseline		4 grammes

or

Ichthyol	1½ grammes
Salicylic acid	½ gramme
Oxide of zinc	2 grammes
Lanoline	5 grammes
Vaseline	10 grammes

The patient should be warned against all irrigation with antiseptic lotions or even with simple water. Water does not agree with such ears as these; their toilet must be carried out by the use of liquid vaseline or very warm alkaline lotions, followed by careful but non-irritating drying.

The acute attacks call for rigid vegetarian diet, and syringing out of the meatus, under the guidance of the forehead mirror, by means of Hartmann's cannula, with a solution of nitrate of silver (1 in 2,000), bicarbonate of soda (15 per 1,000) or chamomile water. Subsequently, dressings moistened with chamomile water may be used after the application to the meatus of an ointment containing oxide of zinc, such as:—

Oxide of zinc	2 grammes
Glycerole of starch	āā 5 grammes
Lanoline	
Vaseline ..	

Orange flower water added drop by drop, until the consistency of an oily cream is reached.

The introduction of ointments of dense consistency or in large quantity into the auditory meatus should be avoided, as the cleansing would become extremely difficult.

CHAPTER II

ACUTE SUPPURATIVE MEDIAN OTITIS

A complete study of acute median otitis naturally does not enter into the plan of this work. We desire merely to recall for the non-specialist the therapeutic indications.

There is one which comes before all others, namely, that for early paracentesis. An otitis which has been allowed to rupture spontaneously runs a great risk of never healing and of developing into a chronic otorrhœa;[1] this passage into chronicity must be avoided at any price.

Therefore, any soldier who is suspected of being the subject of acute otitis should be referred to a neighbouring specialist, without waiting for the appearance of a discharge; this is the best means of preserving efficiency; he can be sent back to his regiment immediately if it is found to be a case of simple otalgia; and, judiciously treated, can be rapidly and completely cured should the case be one of genuine otitis.

The doctor should suspect acute median otitis when he finds the three following symptoms occurring together: otalgia, pyrexia and deafness.

[1] See *Progrès Médical*, 1917, No. 11, *Pourquoi une otite moyenne aiguë devient-elle chronique?* By H. Bourgeois.

The pain of the otitis is very severe, progressively increasing and pulsatile; it is aggravated by pressure on the tragus (the pressure being transmitted to the tympanic membrane) and over the antrum [1] and the tip of the mastoid process; the otalgia from a furuncle is aggravated by manipulation of the meatus; reflex otalgias are unaffected by any of these procedures; the discomfort of temporo-maxillary arthritis is revealed by palpation of the joint and by lateral movements of the maxilla. Pyrexia is always present when suppuration comes on.

The deafness points to a deep-seated aural cause for the otalgia; there is no median otitis without marked deafness.

Thus there is no need for the forehead mirror or the speculum in order to diagnose a case of otitis and to send the patient to a specialist.

The latter will realise the indications for paracentesis; we need not remind him of them, or of the technique.

We will, however, take the opportunity of pointing out our preference for general anæsthesia under chloride of ethyl to the local deadening of sensibility by means of Bonain's solution. The former is quicker, more convenient, more certain, and prevents all useless traumatism of the tympanic membrane.

After paracentesis, we prefer dry aseptic dressings, according to the well-known technique; every case of otitis is in the first place monomicrobic; Lermoyez has shown, by statistics, that by avoiding secondary

[1] The participation of the mucous membrane of the antrum in the inflammatory process is nearly always a phenomenon of acute otitis. Mastoiditis only exists when there is mastoid osteitis. The pain when it first occurs must be due to a slight periostitis accompanying the antritis.

infection patients are cured in the minimum amount of time.

We reserve antiseptic irrigations for profuse purulent discharges, which only manifest themselves after several days, and for those cases where dry aseptic dressings are not available.

The advantages of this early paracentesis must be insisted on: the infection has had no time to spread, the membrane is incised at a spot favourable for evacuation of the pus, the wound is linear, and it cicatrises easily without deterioration in the texture of the tympanic membrane. If we wait for spontaneous rupture mastoid and endo-cranial complications are more liable to occur; the opening is not always situated at the most dependent point; hence putrefaction, retention, chronicity; the perforation may be too small and the drainage of the tympanum unsatisfactory; it may be too large and regeneration will be impossible or defective, for a perforation occurring spontaneously would not be linear; it is due to loss of substance from necrosis of the tissues; it will not close, or if it does so, it will be by the formation of an atrophic cicatricial area, devoid of the normal elasticity of the tympanic membrane.

An otitis properly treated will generally cease in two or three weeks. A purulent discharge which has no tendency to disappear at the end of a month, should direct attention to the naso-pharynx and the mastoid region. In the naso-pharynx adenoids, a persistent focus of infection, should be sought for and, if present, treated; the possibility of a latent osteitis in the mastoid process must be kept in mind; this would be indicated only by a slight evening rise of temperature and a minimal tenderness on pressure;

opening of the mastoid cells is then urgently called for.

Should a case of otitis, in which suppuration has already become established, come before the doctor, he should all the same refer it to a specialist, so that the latter may apply clean dressings, supervise the drainage and assure cure in the shortest time.

CHAPTER III

CHRONIC SUPPURATIVE MEDIAN OTITIS

The number of soldiers suffering from otorrhœa is considerable; we should like to remind medical officers of regiments and ambulances of the signs which indicate the necessity for sending such patients to the specialist, and for the latter we shall point out certain diagnostic considerations and certain therapeutic indications; in particular, the elements of an operative technique, still little known, which has recently formed the subject of a work by one of us (Sourdille) and which is of interest at the present time.

Diagnosis of chronic otitis in general.—There are three symptoms which lead the patient to consult the doctor, viz. the otorrhœa, the deafness and the pain.

The suppuration is the fundamental symptom; it is very variable in quantity, influenced by naso-pharyngeal inflammatory attacks and the absence of local hygiene. The quantity is by no means in proportion to the seriousness; certain scarcely perceptible discharges are more dangerous than others which are profuse. Fetor and the presence of blood call for transference of the patient to a specialist.

Old-standing deafness in addition to a discharge of pus in the meatus, bears witness to a lesion of the middle ear; it must, however, be remembered that simple external otitis with obstruction of the meatus has this syndrome temporarily.

The pain is not the sharp suffering of a furuncle or of an acute otitis; it takes the form of a sensation of heaviness in the region of the ear, of hemicrania, of pseudo-migrainous crises; it draws attention to possible complications and justifies transference to a specialist who will determine its reality and its significance.

Finally, if on brief otoscopic examination, after cleansing the auditory meatus, a perforation of the membrane is discovered, it points to the origin of the suppuration being in the tympanum. To try to carry out this cleansing by the dry method is to lose time and to cause the patient useless suffering; the meatus should first be washed out with a pear-shaped ear syringe or a douche, then with Hartmann's cannula, using Labarraque's Solution diluted with warm boiled water; then dried, and the tympanic membrane wiped with a fine wool-holder coated with cotton-wool moistened with liquid vaseline. A clear view of the perforation will generally be obtained. Some cases, however, present special difficulty.

Extensive destruction of the membrane with absence of the malleus may lead to the inner wall of the tympanum being mistaken for the membrane; on touching this promontory gently with a probe it is found to be hard and resistant; if the probe is bent before being introduced, its bent end may be passed upwards and backwards internal to the tympanic

ring, and it comes against a bony ridge when it is pulled outwards towards the observer.

A perforation, the edges of which are stuck to the inner wall, is imperceptible at the first glance; this is especially the case with regard to many perforations in the postero-superior quadrant, the inferior edge of which adheres to the promontory; a bent probe again averts any mistake; if, on trying to direct it towards the aditus, its course is impeded, there exists simple retraction of the membrane; if it penetrates, there is loss of substance.

A small perforation covered by a crust may escape notice, especially when at the level of Shrapnell's membrane; we must not feel satisfied until the whole of the deep part of the meatus has been thoroughly cleansed with liquid vaseline.

The perforation may be completely filled up by a fleshy granulation, and the lumen of the meatus may even be occluded by a large polypus, the surface of which has the appearance of epidermis; a probe will go round this granulation or polypus, and it will often cause it to bleed.

The existence of a tympanic perforation must not be denied on account of an absence of the "Valsalva" perforation sound, the orifice of the tube may be closed by the sticking together of its walls; tympanic adhesions may prevent the air from penetrating into the meatus.

To sum up, it is easy to diagnose chronic otitis; thorough cleansing and a good light will show the tympanic membrane to be whole if the suppuration is coming merely from the integuments of the meatus.

So as to omit nothing, we will mention a mastoid fistula opening into the meatus, and of which we

have already enumerated the principal characteristics when dealing with the subject of furuncle. Such a mastoid fistula with, at the same time, an intact tympanic membrane, is a rare variety of acute mastoiditis. It calls for immediate opening of the mastoid process. If the fistula occurs simultaneously with chronic otitis its presence indicates chronic mastoiditis and demands radical operation and opening up of the petro-mastoid region.

Fig. 1.—Fistula of the posterior wall of the meatus, and the granulations covering it.

Diagnosis of the different varieties according to their localisation.—The middle ear is an eminently complex cavity, having distinct parts; the course and the treatment of an aural suppuration vary entirely according to the region of the tympanum in which it has its origin. These different types of otitis classified according to the localisation, correspond fairly well to the different varieties of perforations of the tympanic membrane.

Tubo-tympanic suppuration.—Anterior and inferior perforations.—The anterior part of the tympanum, which is close to the tubal orifice and the last part of the Eustachian tube, contains a number of mucous glands, the culs-de-sac of which are liable to become the seat of a chronic infection; the latter is kept up or awakened by pathological changes in the naso-pharynx, which are injurious both from their own chronic or recurring infectivity and from the state of congestion which they keep up; adenoid vegetations and enlarged posterior extremities of the turbinals,

etc., come foremost in causing this. Many patients, especially young children, literally "blow their noses" into their ears.

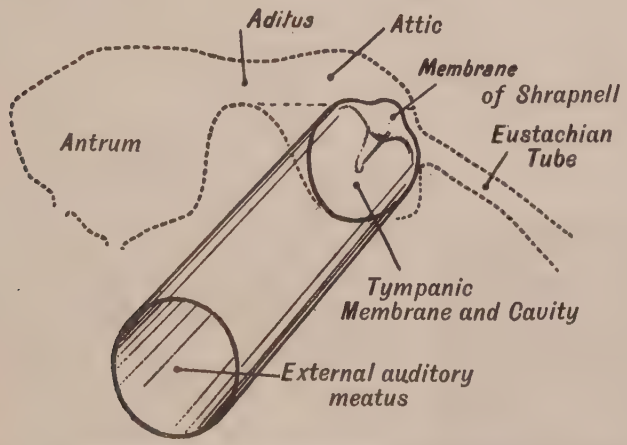


FIG. 2.—Scheme of the three storeys of the middle ear and of the portion directly visible on otoscopic examination.

The perforation may be antero-inferior, inferior or at the same time antero-inferior and postero-inferior; in the last case the perforation is reniform

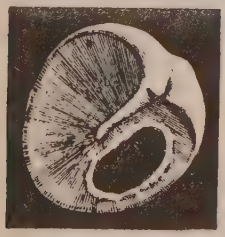


FIG. 3.—Antero-inferior perforation of tympanic membrane.

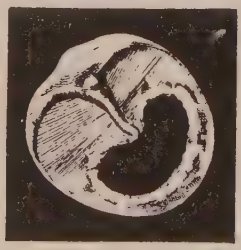


FIG. 4.—Reniform perforation of tympanic membrane.

in appearance, the depression corresponding to the handle of the malleus.

It is more often antero-inferior, opposite the orifice

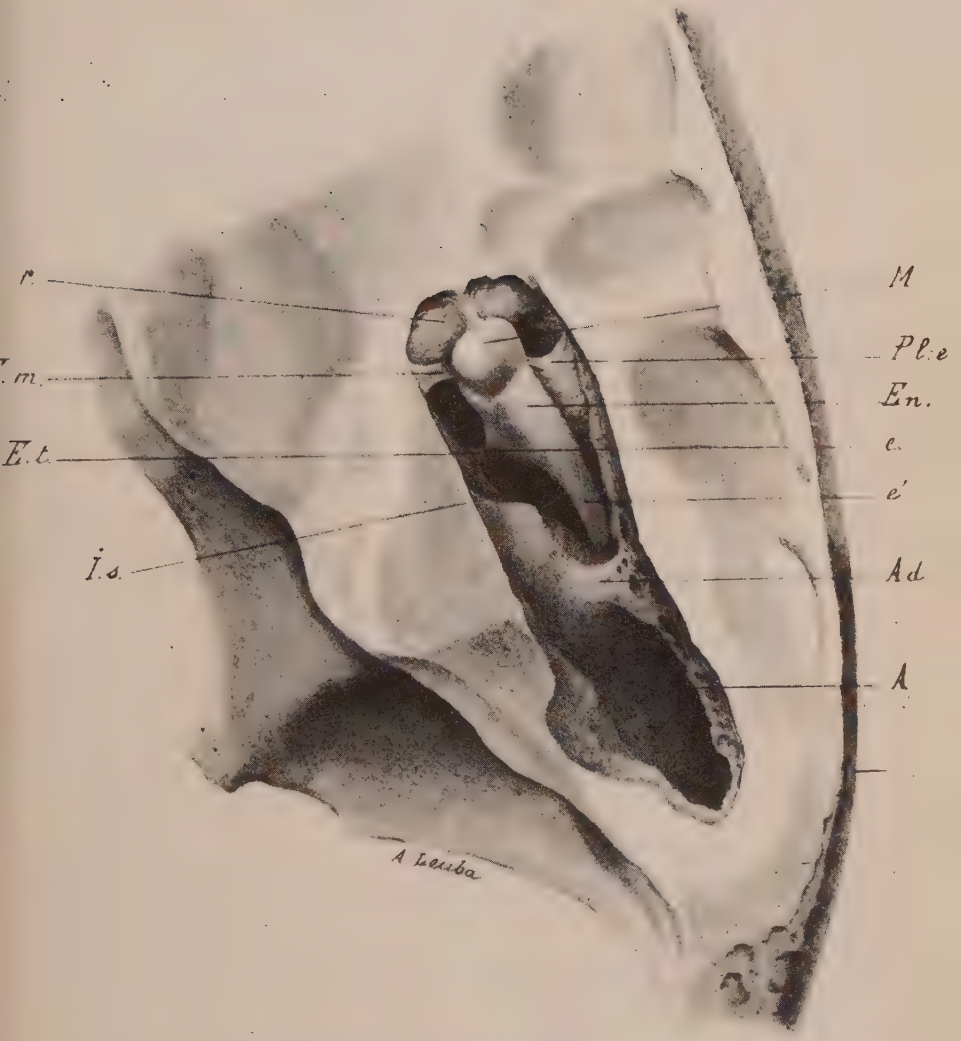
of the Eustachian tube. The discharge, rather mucous than purulent, is driven from the Eustachian tube by each effort of "Valsalva." The membrane is normal, or more or less thickened; the lower part of the drum is vascular, and sometimes there are granulations, but no deep-seated lesions. There is absence of pain and of general symptoms. The deafness varies generally with the amount of discharge, which in its turn depends on the condition of the naso-pharynx.

FIG. 5.—Postero-superior tympanic perforation.

Through the perforation can be seen the descending branch of the incus and its articulation with the stapes.

Attico-tympanic suppuration.—Postero-superior perforation.—The anatomical arrangement (see Plate I) explains how precarious is the drainage of an attic suppuration by way of the tympanum; the two cavities communicate with each other by a narrow cleft, a real attico-tympanic isthmus, bounded on the inside by the inner wall of the tympanum and on the outside by the body of the incus and the head of the malleus. The slightest congestive swelling of the mucous membrane produces stagnation of the pus and secondarily ulceration, osteitis, chronicity. The perforation occupies the postero-superior quadrant or the whole of the posterior segment. The pus is inspissated and fetid. There are often granulations or polypi; multiple, sessile and small granulations bear witness to ulceration of the mucous membrane and to a superficial osteitis arising from the stagnation of the pus from above; polypi obtrude themselves at the level of the posterior edge of the tympanic

Plate I



View of the postero-superior aspect of the ear after ablation of the tegmen tympani et antri.

A. Antrum.
Ad. Aditus.
En. Body of the incus.
e. Its descending process.
e'. Its horizontal process.
P.l.e. Lateral fold of the incus.
M. Head of the malleus.
T.m. Tendon of the tensor tympani.
r. Its mucous covering.
Et. Stapes.
Is. Attico-tympanic isthmus.

Plate II

Suppuration in the attic.

It is to be noted that the bony septum is fixed against the inner wall of the attic. The attico-tympanic isthmus has disappeared; the external attic is much increased in size.

M. Head of the malleus.
En. Partly necrosed incus.
P.m.l. Perforation of Shrapnell's membrane and necrosis of wall of attic.
Att. ext. External attic.
Ad. Aditus.
A. Antrum full of cholesteatomatous débris.

(*To face p.* 21.

ring, most often arising from the region of the aditus and the incus. Treatment confined to the accessible visible lesions is not sufficient to dry up the otorrhœa, the lesions at the deeper part of the tympanum may be cicatrised and pus can be seen still oozing out from the attic or the antrum; in order to verify this, the perforation should be plugged with a little strip of gauze, the upper surface alone of which is found to be stained with pus next day.

The presence of attico-tympanic suppuration indicates the possibility of the risks of retention; a large polypus, or a plug of dried pus, may be the cause of such retention which manifests itself by headache, tinnitus, vertigo; the prognosis is more uncertain than in the preceding condition, and all the more uncertain as the suppuration very often reaches the mastoid antrum.

FIG. 6.—Complete loss of tympanic membrane.

Extensive destruction of the tympanic membrane with granulations on the floor of the drum.

Tympanic suppuration.—Central perforation.—Complete loss of tympanic membrane.—A like purulent discharge may indicate the direct continuation of an acute otitis which has been neglected. The acute affection may have been virulent and have produced great destruction at the time; but more often an infection which, on the contrary, is sluggish when left to itself, has brought about necrosis of a considerable portion of the membrane; such is the origin of very many of the otorrhœas of childhood; finally, the membrane is, sometimes, of such a fragile texture that it is seen to melt as it were, under the action of slight disease.

Such a perforation may indicate either a simple suppuration in the large cavity of the middle ear, kept up by faulty hygiene or defective treatment, or more complicated lesions in which the adjacent cavities participate; the diagnosis will be established by degrees according to the result of rational treatment.

Suppuration in the attic and attico-antral suppuration.—Perforation of Shrapnell's Membrane.—A perforation of Shrapnell's membrane bears witness to a suppuration in the attic, to which the pathological structure gives a particular appearance. Plate II presents a view of the attico-antral region, and it shows some important lesions in the antrum, the aditus and the external attic; there is osteitis on the inner surface of the wall of the attic and the outer surface of the incus and of the malleus; further, the relation of the two attics is reversed; the osseous septum formed by the body of the incus and the head of the malleus is adherent to the inner wall of the tympanum. In this way the *internal attic has disappeared, as well as the attico-tympanic isthmus; there is no further communication between the upper storey and the tympanum;* the pus pours directly into the external auditory meatus (Plate II).

The perforation is situated directly above the short process of the malleus; it is occasionally covered by a crust of dried pus. The loss of substance often encroaches on the osseous framework and thus becomes much larger than the membrana flaccida itself. A small polypus is often present. Inflation by Valsalva does not pass through. Suction with Siegel's speculum sometimes draws out a drop of pus. Prognosis is uncertain on account of involvement of the antrum,

the close proximity of the meninges, defective drainage, and the impossibility of approaching the lesions by the natural routes.

Diagnosis according to the stage and extent of the lesions.—*Lesions of the mucous membrane.*—In the first stage of chronic otitis the mucous membrane is thickened, with some oozing; at a later stage it ulcerates; it then bleeds at some point and is more or less granular; when a granulation enlarges and becomes pedunculated, it is called a polypus.

Osteitis.—The mucous membrane does not long remain ulcerated without the subjacent bone becoming infected. Superficial osteitis shows itself by fleshy granulations; the recognised sensation of bare bone can be felt by the probe, a very painful exploration, often useless for diagnostic purposes.

Granulations and polypi.—An osteitis which has extended to a slight extent, becomes a "bed" of red, sessile and bleeding granulations. If it is limited to one point, the fleshy granulation, under the action of gravity, develops into a polypus inserted by its superior pole; it is sometimes very large. There are, therefore, two kinds of polypi, those which reveal a simple local œdematous degeneration confined to the mucous membrane, and those which bear witness to osteitis; the latter are the more numerous. When the osteitis remains superficial, it preserves this aspect of a bare sprouting surface; when the infection reaches the deeper part of the bone, the latter becomes necrosed and has the appearance of an absolutely bared region, like ivory.

Cholesteatoma.—An account of the last kind of lesion is of considerable importance; it is that of cholesteatoma, which is the name given to the result

of an epidermic proliferation taking the form of clumps or small collections of scales, with a "mother-of-pearl" appearance; they are met with almost exclusively in attico-tympanic and attico-antral suppurations. The epidermis of the meatus, passing through the perforation, invades the suppurating cavity and covers the ulcerated surface; instead of being thrown off in the normal manner, it proliferates abundantly and desquamates continually under the form of scales which adhere together. When masses, thus formed, can find no outlet for extrusion by way of the meatus, they increase where they are, producing around them a rarefying osteitis; meninges, membranous labyrinth, and facial nerve become in this manner exposed, and all the complications of otitis may follow.

Accessible lesions.—Tympanic and tubo-tympanic suppurations are accessible to our means of investigation; they only present, in general, changes in the mucous membrane or superficial lesions of the bone.

Inaccessible lesions.—Attico-tympanic suppurations reveal to us, through the posterior or the postero-inferior perforation, osteitis of the floor, that of the posterior framework (bony casing) of the facial nerve, and granulations indicating osteitis of the long process of the incus; the incus may be eliminated; though not perceptible, suppuration in the attic, the aditus, and the mastoid antrum, must be suspected; cholesteatomatous material should be searched for in the water used for syringing.

Perforation of Shrapnell's membrane and lesions of the ossicles.—Perforations in Shrapnell's membrane show us only the exposed malleus, but we know that lesions of the external attic, the aditus and the mastoid antrum are the rule; otoscopic examination does not

reveal this deep-seated extension of lesions which alone could account for the abundance of the discharge; but, on the other hand, it furnishes us with some important data as to the state of preservation of the ossicles and the continuity of the chain—a very important point in the functional prognosis and the indication for operation.

The lesions of the ossicles are habitually proportional

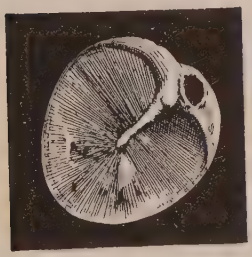


FIG. 7.—Perforation in Shrapnell's membrane.

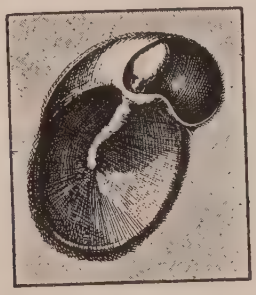


FIG. 8.—Perforation of Shrapnell's membrane with disappearance of the anterior part of the wall of the attic.

The malleus is in its place. The suppuration has yielded to medical treatment. Hearing for low voice at 9 metres.

to those of the walls of the attic at their level.

Four types of case may present themselves:—

(a) *Perforation limited to Shrapnell's membrane.*—The ossicles may be affected with osteitis, but the lesion is superficial and the continuity of the chain is not broken.

(b) *Perforation of Shrapnell's membrane with osteitis and elimination of the anterior half of the wall of the attic.*—The head of the malleus is alone necrosed and more or less diminished in size; the chain of ossicles is still continuous.

(c) *Perforation of Shrapnell's membrane with total elimination of the wall of the attic*, that is to say, *spontaneous total atticotomy.*—The head of the malleus, the body and the horizontal process of the incus have all disappeared. The chain is broken. Deafness has become marked and irreparable.

(d) *Disappearance of the incus*, that is to say, of the bony septum which protects the tympanum; this is often followed by invasion of the latter with suppuration, unless the tympanic membrane is completely adherent to the promontory; but in this case the osteitis extends along the descending process of the incus, reaches the drum and causes a *postero-superior perforation* in addition to the perforation in Shrapnell's membrane.

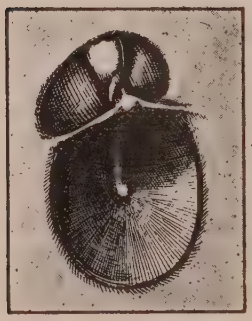


FIG. 9.—Perforation of Shrapnell's membrane and complete disappearance of the wall of the attic.

Complete spontaneous atticotomy. The incus has disappeared; hearing for low voice at 1 m. 50.

Chronic mastoiditis.—Suppuration in the attic revealed by a posterior perforation or by a perforation of Shrapnell's membrane is nearly always complicated by suppuration in the mastoid antrum; we have no means of determining the development of these lesions; only the profuseness of the discharge and the persistence of its fetidity, in spite of treatment, lead to our recognising it. It is in this that the danger of the otorrhœa lies.

Diagnosis of the severity. — We have not sufficient space to study the prognosis and complications of chronic otitis. We must content ourselves with enumerating the *symptoms of danger*, which

demand a thorough examination and often an immediate operation.

Headache disappears after cleansing or removal of a polypus when it is a symptom of a passing retention. Persistent headache must be very seriously considered.

Rise of temperature is a symptom of acute extension of the infection; operation is called for.

Emaciation and asthenia are often indications of extension to the brain.

Paresis and paralysis of the facial nerve call equally for operation.

Vertigo signifies irritation or invasion of the labyrinth; polypi situated at the level of the fenestra ovalis are sufficient to produce this symptom; erosion of the osseous labyrinth is shown by the fistula sign—*i.e.* nystagmus induced by compression of air in the auditory meatus; suppuration in the membranous labyrinth is indicated first by diminution and then by abolition of the caloric and rotatory reflexes. The hearing-tests reveal equally well that there is invasion of the internal ear, by rapid increase of the deafness, lateralisation of Weber to the good side and diminution of bone-conduction.

Differential diagnosis from tuberculous otitis. —Tuberculosis of the middle ear occurs almost exclusively in the subjects of established phthisis; it is rare, one case in two thousand being found by Sourdille in a "centre" set apart for the isolation of consumptives.

It is characterised by its indolence, the multiplicity of the perforations,[1] the profuseness of the suppuration, the extensive progress of the lesions with rapid

[1] For further details see Bourgeois, in *Précis de Pathologie Chirurgicale*, Vol. II. Masson et Cie., éditeurs.

invasion of the Fallopian Canal and the internal ear.

Therapeutic indications. — **Treatment of the severe forms.** — Patients who present any of the dangerous symptoms enumerated above, and particularly signs of endocranial complication, must be operated on immediately ; opening up of the petro-mastoid region is the minimum that should be done for them.

Treatment of the simple forms. — Tubo-tympanic and simple tympanic suppurations, with a large perforation, admit of a favourable prognosis ; they should not interfere with military service any more than they stand in the way of the occupations of civil life. We have, however, to intervene for the purpose either of instituting a *rapidly* curative treatment, of alleviating a temporarily aggravated condition or of advising with regard to aural hygiene.

Curative treatment.—Suppuration is often kept up either by the condition of the naso-pharynx or faulty treatment.

It is frequently sufficient to operate on adenoid vegetations and posterior extremities of the turbinals, and to disinfect the nasopharynx, in order to cause the otorrhœa to dry up in a few days.

The stopping of all introduction of water in the course of the toilet, of all irrigation or so-called antiseptic instillations, will have the same satisfactory result, provided preliminary disinfection is carried out followed by the application of a dry antiseptic dressing.

These simple means may be insufficient ; perhaps there are granulations to cauterise or a polypus to remove, but in this case also the cure is rapid.

At other times diffuse lesions of the mucous membrane demand special treatment; aural baths of nitrate of silver (1 in 40), instillations of boricated alcohol, insufflation of boracic acid powder, or applications of a solution of chloride of zinc, there being so many means that choice must be made according to the particular case.

Palliative treatment.—After such treatment, the otitis either dries up or it merely diminishes in quantity; treatment in hospital should not continue indefinitely; it should even be of very short duration; the patient should be sent back to his regiment, taking with him the otological slip shown at the end of this volume, on which are mentioned the exact diagnosis and appropriate treatment, such as cleansing of the meatus by the dry method, followed by a bath of peroxide of hydrogen or the instillation of boricated alcohol.

Treatment of cases with a tendency to become worse.—The prognosis in attico-tympanic and atticoantral suppurations must be reserved. If certain very mild and subsiding cases appear to be suitable for **combatant service,** other more serious ones, involving total incapacity, call for almost perpetual hospital treatment and are eligible for **discharge** in conformity with ministerial regulations.

Many of these patients go to make up the valuable "**auxiliary**" forces, where supervision and occasional palliative treatment can be carried out.

Finally, it is advisable to cure these patients surgically and to render them **fit for combatant service.** But they cannot all be operated on. Curative surgical treatment must be reserved for those whose moral and physical value renders them capable

of making good soldiers. The functional point of view must also be kept in mind and the question asked as to whether the hearing of the operated ear will be sufficient after the suppuration has been cured.

We propose considering the palliative and the curative treatment.

Palliative treatment. — *Fleshy granulations.* — Chemical cauterisation of the limited lesion is the best treatment, and chromic acid is the best caustic ; but it dissolves and must be handled with precaution, either in the form of a very small crystal or deliquesced at the end of a blunt probe, or in a concentrated solution on a fine wool-holder. The field of operation should be previously cleansed by syringing with Hartmann's cannula and carefully dried. Another syringing will remove any excess of chromic acid if this is thought necessary in order to prevent secondary painful phenomena.

For granulations which bleed only very slightly a solution of chloride of zinc (1 in 10) or a solution of equal parts of formol, alcohol and glycerine may be used ; the latter is fairly efficacious but causes pain.

Large fleshy granulations offer resistance to the caustics ; they can be curetted, but this curetting is an operation which requires great precautions of antisepsis in the first place, and of asepsis, in order not to bring about complications ; Luc has, for some time, pointed out the danger of incomplete operations in an infected area ; besides, this curetting by the natural routes is always an incomplete operation, for large and recurrent multiple granulations are always symptomatic of a suppuration which has extended beyond the accessible zones. Accordingly, for these patients we prefer to advise discharge or opening

up of the petro-mastoid region, according to the causes.

Polypi.—Local anæsthesia, removal with a snare worked by a lever or with a curette embracing its pedicle, and at the same time applications of a solution of chloride of zinc to the subjacent zone of osteitis, are indicated.

Cholesteatoma.—A limited lesion close to the aditus, giving rise to an almost insignificant amount of suppuration and to the production of small cholesteatomatous masses which are ejected through a sufficiently large perforation of the posterior segment, can be treated by syringing with Hartmann's cannula, which will drive out the cholesteatoma when there is need. Each syringing is followed not only by careful drying, but by dehydration effected by means of "drops" of alcohol. The surface of the osteitis is cauterised with chloride of zinc, after the cholesteatoma is removed.

In the case of a perforation confined to Shrapnell's membrane, extraction of the cholesteatoma is impossible, because the perforation is too narrow and does not permit of the stream of water being directed in every direction; even the water which is injected is retained in the attico-antral cavity; hence this treatment is quite insufficient.

Curative treatment.—Opening up of the petro-mastoid cavity.—For attico-tympanic suppurations there is only one operative procedure, namely, *complete opening up of the petro-mastoid region; partial opening up is to be rejected in these cases.*

We will not enter into the details of the classical technique of the present day. We will merely say that it is necessary to operate very freely and to shave

off as much as possible of the base of the bony casing of the facial nerve. Finally, curetting of the inner wall of the tympanum must be performed with a light touch.

The patient, after healing has taken place, must be under supervision. The epidermis which covers the new mastoid cavity is fragile and ulcerates easily. The attention which it requires is, however, very simple, namely, gentle removal of the crusts which have formed on the surface, with a swab moistened with liquid vaseline.

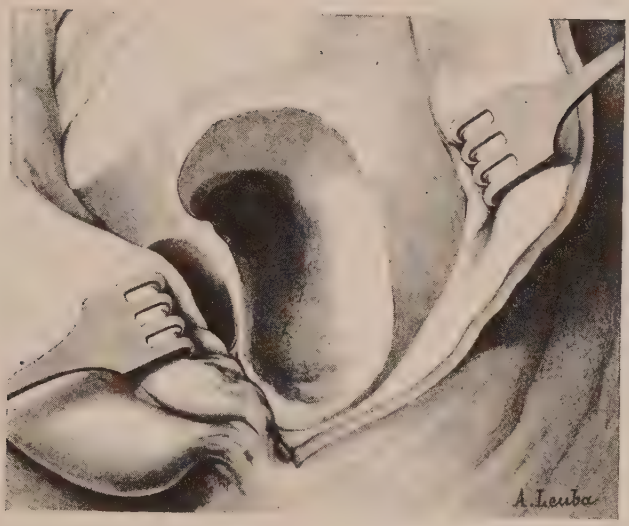
Partial opening-up. — Attico-antral suppurations with perforation in Shrapnell's membrane are amenable to the partial operation. One of us in a recent work [1] has endeavoured to show why ossiculectomy (until now suggested as the treatment for these suppurations) was a mutilating procedure, incapable of bringing about a lasting cure. He states that the spontaneous mode of cure of these suppurations by *spontaneous atticotomy* brings about inevitable rupture of the chain of ossicles and consequently an irreparable loss of part of the auditory function, and suggests that we should not wait for this natural course, but that *surgical opening of the attic should be practised.* Here, as in acute otitis, spontaneous rupture spells destruction of organs essential to the auditory function and *it must be forestalled.*

Atticotomy through the meatus being practically impossible and dangerous, it must be effected by the *trans-mastoid route ;* this amounts to performing a partial mastoid operation by Bondy's method.

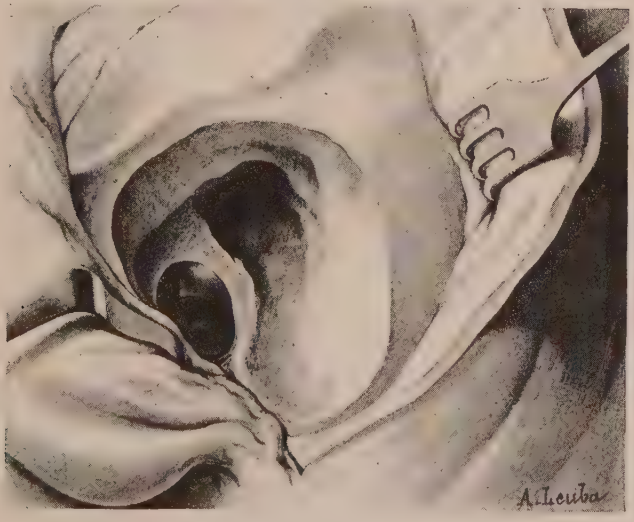
Operative Technique.—The operation consists

[1] M. Sourdille, *Trépanation mastoïdienne élargie et atticotomie transmastoïdienne.* Doin, éditeur, Paris.

Plate III

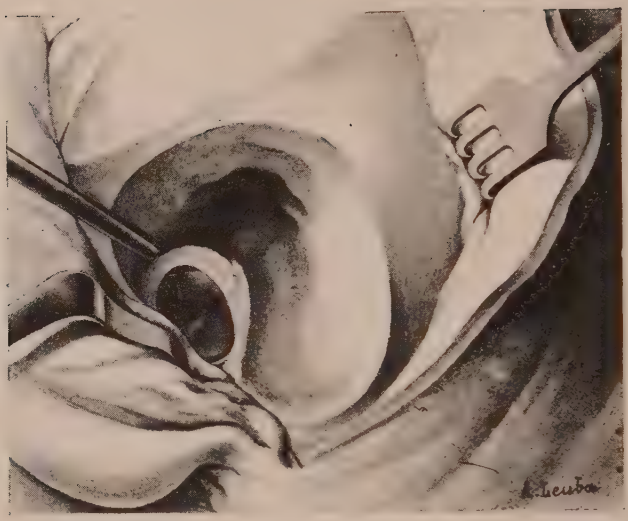


(1) Trephining of mastoid process has been carried out; the roof of the antrum, freely exposed, is directly continuous with the superior wall of the trephine orifice.

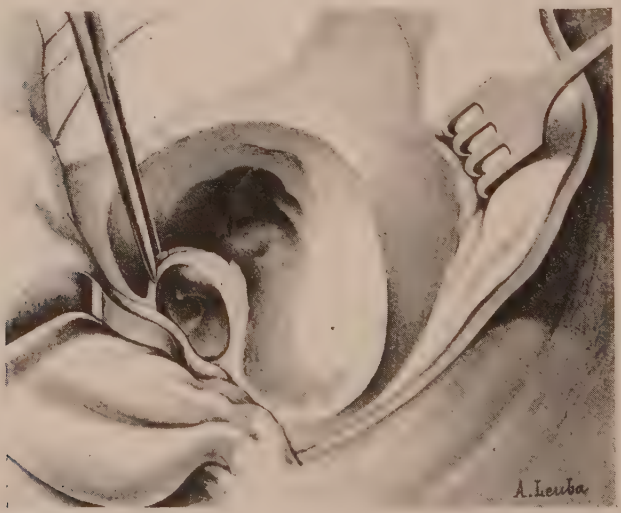


(2) *1st stage.—Incomplete resection of the roof and of the posterior wall of the meatus.*—The external wall of the attic is no longer present except as a bony lamella of 3 mm. in thickness, and perfectly smooth.

Plate IV



(1) 2*nd stage.—Superior opening of external attic.*—A gouge, of the 3 mm. size, removes in small fragments the superior part of the plate. The roof of the aditus and of the tympanum forms the superior limit which must not be overreached. The osseous peri-tympanic ring protects the chain of ossicles.



(2) 3*rd stage.—Breaking-down of the bridge.*—It is carried out at the *anterior* part of the osseous peri-tympanic ring, *in front of the head of the malleus.* Position of the gouge for the carrying out of this stage.

[*To face p.* 33.

of three parts—opening of the antrum, opening of the external attic, and treatment of the soft parts.

First Part.—Opening of the antrum.—This is performed in the same way as in the complete operation; care must be taken to detach the membranous meatus gently and to avoid wounding the tympanic membrane.

Second Part.—Opening of the external attic.—This is a delicate part of the operation; it consists in removing, without touching the ossicles, the external wall of the attic, formed not only by the wall proper of the attic, but also by the roof of the external auditory meatus. The extent of the bone to be removed, from the meatus to the attic, is at least 15 mm., with a vertical thickness of from 5 to 6 mm.; its ablation must be methodical if the success of the operation is not to be compromised.

The technique which we have proposed consists of four stages.

1*st stage.—Incomplete resection of the roof of the meatus.*—Without resorting to heavy blows, the gouge must be driven fairly rapidly; it transforms the osseous wall, thick and oblique, into a well-defined thin level plate, on which the fine gouge can work with precision and without danger of slipping (Plates III and IV).

Exposure of the supra-jacent dura mater must be avoided and to this end *the direction of the roof of the antrum and of the aditus must be followed,* the level of which is indicated by the orifice of the mastoid trepanation.

2*nd stage.—Superior opening of the attic.*—This is performed by degrees from *behind forwards,* with a fine gouge of 3 mm. in size, which removes the whole of

the superior part of the plate just made ; the bone is spongy and is easily cut by *gentle blows, for at all costs a slip into the deep part must be avoided.* The gouge is held all the time above the ossicles which are protected by the osseous peri-tympanic ring, the next part to be resected.

3rd stage.—Breaking-down of the bridge.—This is not carried out in this instance as in the complete mastoid operation, from its posterior part to the level of the incus ; the bone is friable and the gouge, by its blow, nearly always detaches a small piece of bone, which, driven inwards, risks dislocation of the incus. It is at its anterior part, in front of the head of the malleus, that the gouge cuts it through.

4th stage.—Resection of the tympanic ring.—The part situated in front of the ossicles is first cut away, then the posterior part ; during this stage the gouge should be held as nearly as possible parallel to the ossicles (Plate V).

Third Part.—Treatment of the soft parts.—The attic is completely opened ; by means of syringing

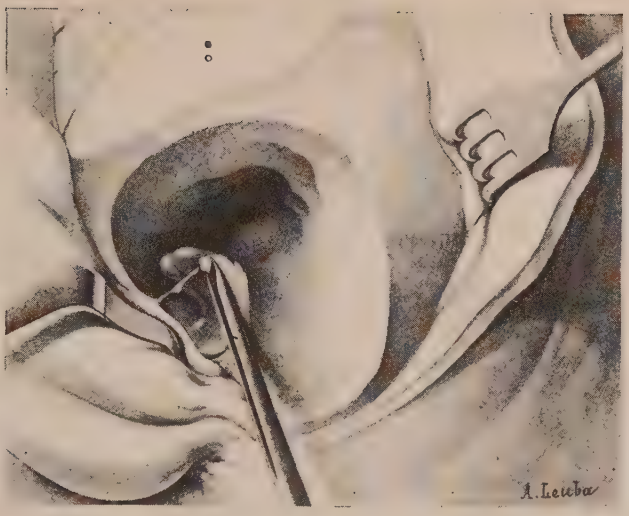
---

EXPLANATION OF PLATE V

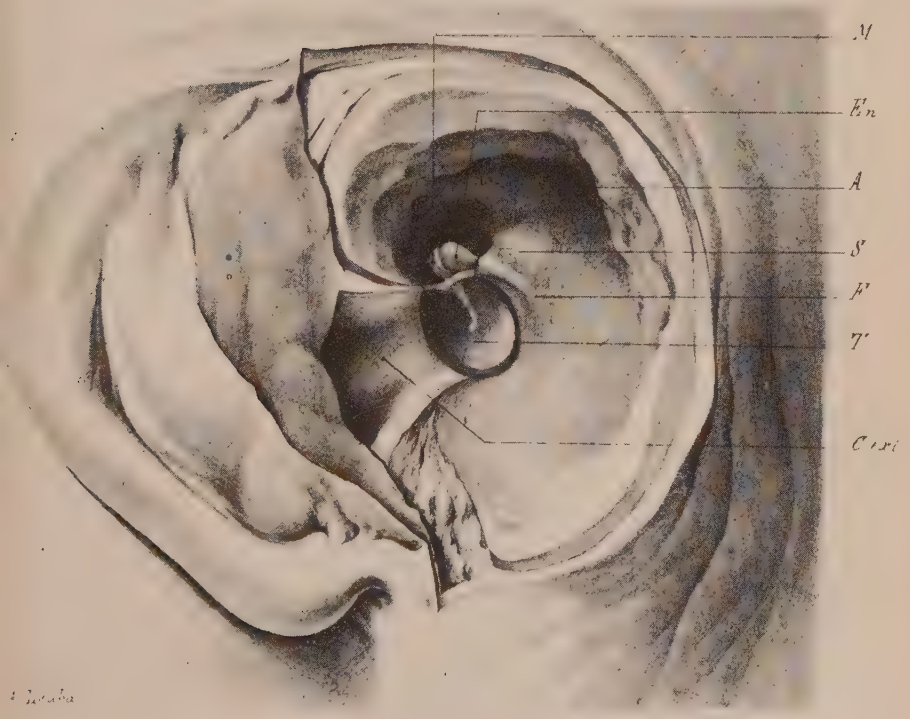
FIG. 1.—*4th stage.*—Resection of the tympanic ring. *It is carried out in small fragments from before backwards. Position of the gouge inclined parallel to the surface of the ossicles.*

FIG. 2.—*The completed operation : the bony casing of the facial nerve is shaved off as much as possible. The plastic flap is resected so as to show the operation cavity better.*

M. Malleus.
En. Incus.
A. Antrum.
S. Projection of the horizontal semi-circular canal.
F. Facial nerve.
T. Tympanic membrane.
C. Anterior wall of the external auditory meatus.



(1) *4th stage.*



(2) *Completed trans-mastoid atticotomy.*

with Hartmann's cannula, the cholesteatomatous débris which block it up are removed. The ossicles are sometimes hidden under the granulations which cover them; we must not be insistent in clearing them; this can be done during the post-operative treatment.

We conclude by cleaning up the mastoid wound, and carrying out a large "plastic" of the meatus with an inferior flap, as in the complete mastoid operation, with suture of the retro-auricular wound. Finally the operation cavity is plugged with *iodoform gauze.*

POST-OPERATIVE TREATMENT.—This is of primary importance for the success of the procedure. Regular epidermisation of the operation cavity and cicatrisation of the attic and ossicles must be assured.

The dressing should be repeated every day.

In the first place the operation cavity and, above all, the attic should be syringed out with Dakin's liquid or Labarraque's solution well diluted with sterilised water (2 per cent.) by means of Hartmann's cannula, followed by careful drying and cauterisation, when necessary, of the granulations on the ossicles with a solution of chromic acid (1 in 30) or chloride of zinc (1 in 20), and finally dressed with small strips of iodoform gauze, as in a radical mastoid operation. After a week plain sterile gauze alone should be used for the dressing.

We repeat that the dressing should be carried out every day; without this there is a risk of the wound becoming infected and the healing retarded. It is only after cicatrisation of the osteitic lesions that the dressings may be less frequent.

The duration of the treatment is very much the

same as for the complete mastoid operation, from fifty to seventy days.

The hearing reappears suddenly after the first dressing ; it decreases on the following days, and then it increases progressively after cicatrisation and absorption of the connective tissue which may have developed about the ossicles.

Results.—In the last patient operated on, after fourteen years of suppuration in the attic with cholesteatoma, complete cicatrisation took place by the sixty-eighth day after the operation. His hearing for the low voice increased from 0 m. 80 before the operation to 8 metres.

We shall publish later a series of our observations on this proceeding.

It has been reproached with being too full of detail and moreover *paradoxical.*

Full of detail it undoubtedly is, as the resection of the external wall of the attic is a delicate matter, but it is easy after some practice on the cadaver. Is it possible to perform the complete mastoid operation correctly, straightway, without previous practice ?

It is styled *paradoxical* in that it leaves lesions behind and removes healthy tissues. Do we profess, in the course of a complete mastoid operation, to remove all the osteitic lesions which exist on the internal walls of the attic and of the tympanum, particularly at the level of the fossa of the fenestra ovalis or fenestra rotunda ? These lesions heal secondarily, because the operation has done away with retention opposite them. It is the same with the partial opening ; the external ulcerated surface of the incus is here homologous to the inner wall of the tympanum. These lesions heal because they are laid bare and are

directly accessible to modified post-operative treatment.

In short, the *principle* of the partial operation is to treat the attico-antral lesions by exposing the antrum and attic in their entirety, by bringing to light the lesions without any mutilation of the chain of ossicles. The morbid changes in the latter are treated, in full view, in the course of the later dressings.

The result is *cure of the suppuration with preservation of the function of hearing*, an essential condition to secure the patient's intrinsic value. It is for this reason that the operation seems to us so important from the military and social points of view.

Ossiculectomy.—It used to be the classical saying (1) that all otorrhœas remaining uncured after appropriate medical treatment, are amenable to ossiculectomy in the first place, and failing that, to petro-mastoid opening; (2) that caries of the ossicles calls for ossiculectomy.

The first of these indications has met with fewer and fewer partisans, because ossiculectomy is an operation as mutilating as a mastoid opening, and it does not have any effect on chronic mastoiditis, the usual cause of the chronicity of otorrhœa.

The second indication does not exist for us so long as the caries of the enlarged ossicles has not caused rupture of the chain.

According to our opinion, ossiculectomy should find its principal indication in those cases of old-standing otorrhoea with great loss of tympanic substance, where the incus is most often eliminated and the antrum considerably reduced in size by condensing mastoid osteitis. The scanty but obstinate suppuration is often kept up in these cases by caries

of the head of the malleus or of the anterior part of the walls of the attic. The removal of the useless remains of this ossicle may bring about a very rapid cure.

Contrary to the classics, we never practise ossiculectomy when the lesions are situated *on the external surface* of the ossicles, as in suppuration behind Shrapnell's membrane, when the tympanic membrane is intact and the tympanum proper shut off; we prefer to sacrifice the external bony wall of the middle ear, which has no essential functions, and to preserve its contents—the ossicles—which are indispensable organs for the auditory function.

A misunderstanding has long existed between the surgeon who declares himself satisfied when he has arrested a suppuration dangerous to life, and on the other hand the patient who is little concerned with regard to this, but is above all anxious to be able to hear. Both are right, and we must concern ourselves with the preservation of hearing power whilst putting an end to the aural infection; now the curing of suppuration in the attic without destruction of the chain of ossicles ought to improve the hearing; removal of the ossicles when the membrane is intact, aggravates the deafness enormously.

SECOND PART

WOUNDS OF WARFARE

CHAPTER IV

WOUNDS OF THE EXTERNAL EAR

WOUNDS OF THE AURICLE

Etiology.—Wounds of the auricle are fairly frequent and chiefly as the results of bursting of grenades, which generally cause multiple superficial injuries of the face and scalp.

Isolated wounds of the auricle from bullets or fragments of shells are rarer. We have never observed any caused by sword-cuts.

Symptoms.—Every variety is to be seen, from simple scratches of the skin to perforating wounds or tears with partial or total loss of substance.

The wound may be situated on the free margin, the concha, the lobule of the ear or the tragus; a projectile which strikes the auricle perpendicularly buries itself in the mastoid region, the parotid region or the muscles of the neck.

These wounds cicatrise rapidly by reason of the rich vascularity of the part. Sometimes, however,

they suppurate, especially the lacerated ones, where the bruised cartilage is exposed and when the treatment has been insufficient. The infection extends to the cartilage, whence chondritis follows; this is very obstinate and tends to elimination of the cartilage and to unsightly cicatricial contractions.

Loss of the auricle causes a certain amount of difficulty in locating sounds in space; closing up of the auditory meatus by a cicatrised stump affects the hearing injuriously.

Treatment.—The surgeon has a double aim, namely, to prevent infection and perichondritis, and to avoid post-cicatricial deformity.

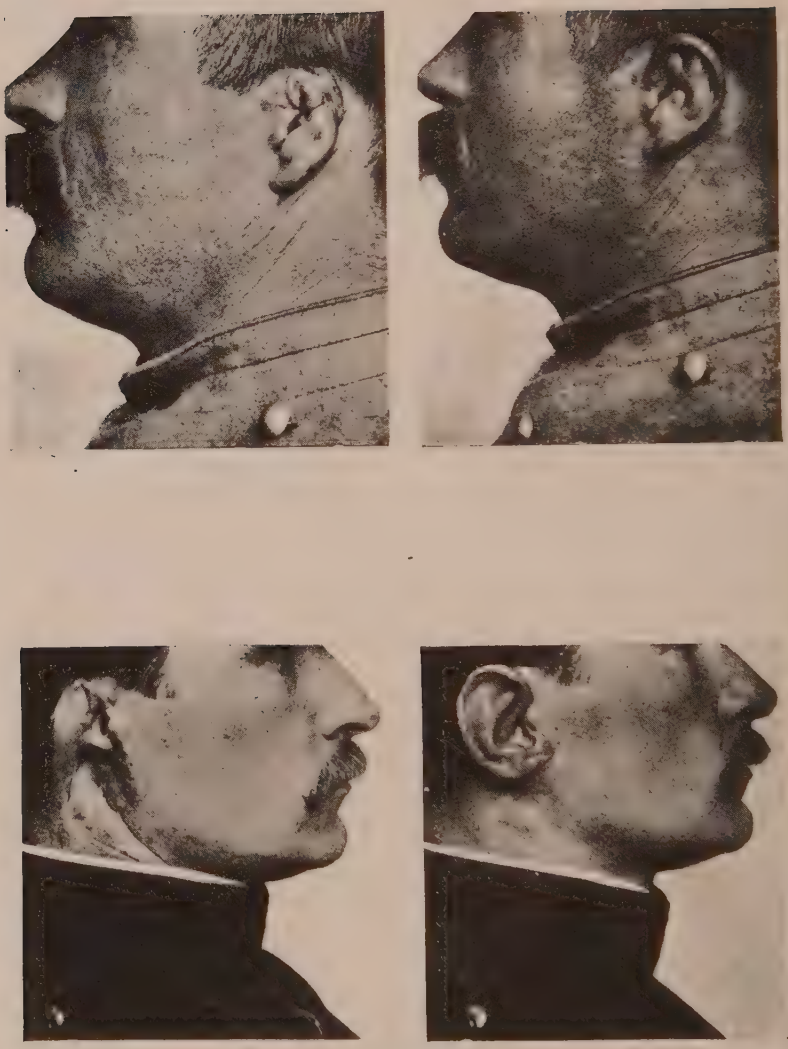
The wound should be carefully *cleansed and sutured* as soon as possible after the injury; the contused parts should be resected with scissors, *but sparingly;* a suture at the perforated parts will prevent overriding of the fragments.

If perichondritis takes place the affected portion of cartilage must be detached and excised as soon as possible with a bistoury; this is the only means of limiting the ravages. Later on, the cicatricial deformity should be treated.

In simple cases, auto-plastic repair, according to Morestin's method (so-called "game of patience") may be attempted; the cicatrised tissue is excised and cutaneous flaps liberated, then sutured one to the other.

But when the loss of substance is extensive and reaches the supporting cartilage, it is preferable to have recourse to a prothetic apparatus to hide the deformity. Pont, principal of the Prothetic Service of the XIVth Region, advocates an apparatus of plastic paste, which the patient models himself in

Plate VI



Prothesis of the auricle according to Pont's Method.

a mould previously prepared; it is kept in position by a special kind of glue. In this way deformed stumps and partial or total loss of the auricle can be hidden.

The figures on Plate VI, kindly lent by the deviser, represent two cases of reparation carried out by this method.

WOUNDS OF THE EXTERNAL AUDITORY MEATUS

Etiology.—Injuries of the meatus are less frequent than those just mentioned, and they arise from the same causes. We will not here consider wounds of the meatus secondary to fracture of the cranium or a blow on the chin.

Pathological anatomy and symptoms.—Isolated lesions of the meatus occur almost exclusively on the external membranous portion.

Injuries of the osseous portion are always secondary to a fracture of the mastoid process or of the tympanic bone and are accompanied by lesions of the middle ear; they will be considered along with injuries of the auriculo-mastoid region.

At the level of the auditory meatus or more deeply situated, either a penetrating wound with a single orifice, or more rarely a perforating wound, may be observed.

The lesion involves only the integuments or includes at the same time the cartilaginous skeleton: this is the usual occurrence.

Otorrhagia and pain induced by movements of the temporo-maxillary articulation are the two signs at the onset. The wound may heal aseptically.

Often, the projectile remains *in situ*, and causes a

suppuration which discharges itself exteriorly by the meatal wound. Healing is slow; the tissues become infiltrated and the cicatrisation brings about a *stenosis* which interferes with audition; this is the great danger connected with an infected wound of the meatus.

Treatment.—Before everything, stenosis must be prevented. The cleansed wound should have its adhesions *divided in the line of the axis of the meatus.* It should be explored with a probe and the projectile extracted, if it has remained near the orifice; then plugging with dry sterile gauze is carried out.

The same division of adhesions and search for the projectile should be made, if suppuration is present. If the position of the wound is not favourable for satisfactory drainage, there should be no hesitation in making a counter-opening at the lowest part of the wound, which will allow of cicatrisation of the meatus.

Treatment of the stenosis.—If simple dilatation by plugging does not bring about any result, recourse must be had to surgical treatment. This consists in making a retro-auricular incision, detaching the auricle and the posterior meatal wall, and excising the cicatricial part. Even this may not be sufficient, and according to the case, it may be found advisable to resect with a gouge a more or less extensive portion of the postero-superior *osseous wall*; the corresponding membranous wall will be excised or simply cut into a flap hinged below which will be turned down below and behind according to the method of "plastic" of the meatus usual in a mastoid operation. The proceedings will be concluded by suturing the retro-auricular wound while the meatus will be plugged until complete epidermisation has taken place.

CHAPTER V

INJURIES OF THE TYMPANIC MEMBRANE AND OF THE TYMPANIC CAVITY

Etiology.—Injuries of the middle ear are of frequent occurrence. One of us has made observations, in an Oto-laryngological Centre in the Interior, of 373 cases of traumatic median otitis out of a total of 6,171 patients examined between April 15, 1915, and October 1, 1916. The actual number is probably less, for certain patients have a tendency to attribute a traumatic origin to old-standing otorrhœas, which have been merely re-awakened; the error, however, cannot be a considerable one.

Foremost comes the frequency of ruptures of the tympanic membrane; and, in addition, many pass unobserved when they are associated with more serious wounds such as lead to the wounded man entering a general surgical department.

Most authors insist on the importance of former tympanic lesions being predisposing causes for injuries of the tympanic membrane; this is rational, but to what extent do they have this effect? It is almost impossible to determine this point for want of previous examinations, and because of the various circumstances accompanying the accident.

The determining cause is a direct shock on the

tympanic membrane. It is produced either by a solid projectile such as a fragment of a shell, a torpedo, a grenade, thrown-up gravel, or else by a violent displacement of the air which follows the deflagration of the explosion—" the air projectile."

Isolated injuries of the tympanic membrane and of the tympanum by a solid projectile, are rare; the curvature of the meatus guards against this; the wounding agent generally causes at the same time lesions of the mastoid region or of the meatus which we will consider in the next chapter.

The " air projectile," on the contrary, is the chief cause of localised injuries of the tympanic membrane and tympanum.

Pathogenesis.—The explosion of a projectile, setting a considerable mass of gas at liberty, causes two phenomena in its immediate neighbourhood, namely, violent driving back of the surrounding air and a sudden elevation of the atmospheric pressure, the latter being all the more intense if the projectile bursts, so to speak, in a closed vessel—a dug-out or a trench.

The projected air enters the external auditory meatus which lies in the direction of the projectile; it comes up against the tympanic membrane which ruptures; the lesion is then unilateral.

Increase of pressure may act on the two tympanic membranes, so that they may burst simultaneously; the lesion is then bilateral.

Thus we think we can explain the fact that those who are injured when in the open nearly always present unilateral lesions, or more marked on one side than the other, whilst those who are injured in the trenches have more often bilateral lesions.

An endeavour has been made to explain, by the inverse phenomena (aspiration and diminution of the atmospheric pressure), the disorders provoked by the bursting of a shell. Where the ear is concerned, we admit the action of compression. Compression is the phenomenon which occurs first; why not admit that it is the most guilty? The reaction is certainly less intense and less sudden than the action. Why should a tympanic membrane resist the latter and yield to the former? Further, the articulation of the incus and the malleus is such that the movements outwards of the tympanic membrane are not transmitted to the liquid in the labyrinth. How are labyrinthine disturbances associated with explosion to be explained, if not by sudden compression?

Pathological anatomy.—Lesions of the tympanic membrane vary from simple contusion to rupture.

Tympanic contusion.—Contusion has been recently described by Saupiquet.[1] We ourselves have noted it several times. It shows itself as a small interstitial hæmorrhage, lenticular in shape and of varying length, which may be situated anywhere on the membrane but more often along the handle of the malleus.

According to this same author it may be situated on Shrapnell's membrane; such a localisation must be rare; we have never observed it. The hæmorrhage becomes absorbed during the following days, leaving the membrane intact, or it is transformed, according to Saupiquet, into a secondary tympanic perforation (??).

Rupture of the tympanic membrane.—More often the

[1] SAUPIQUET, *Lésions de l'oreille moyenne*, "Revue hebdomadaire de Laryngologie," December, 1916.

tympanic membrane ruptures under the violence of the shock.

The resulting perforation is generally an isolated one. We have, however, observed a few cases of double or even triple perforation, one being separated from the other by a little bridge of tympanic membrane.

Its situation is variable; it may occupy one of the quadrants—anterior, posterior, superior or inferior—but it is found most frequently in the inferior and posterior segments. We have never seen one at the level of Shrapnell's membrane; perforations in the flaccid zone are, in our experience, always pathological.

The loss of substance may be central, peripheral or marginal.

The shape varies with the size; it is sometimes punctiform, sometimes linear, sometimes round, oval or reniform when the antero- and postero-inferior quadrants are attacked simultaneously. Almost complete disappearance of the membrane may also occur. The aspect at the outset is characteristic; the edges are torn, indentated, bleeding and surrounded by a narrow hæmorrhagic margin (Molinié).

Later, after cicatrisation, these characteristics disappear and it becomes difficult to distinguish between the traumatic perforation and a pathological one, especially if the tympanic injury has suppurated.

Anatomical course.—The course varies according as to whether the tympanic wound becomes infected or not.

(1) *The tympanic wound remains aseptic.*

The rupture has not been produced by the contact of an infective agent; the curvature and the depth

of the external auditory meatus protect the wound against infection from without.

Two courses are possible—the perforation may close or else the edges may epidermise and the perforation become permanent. Small and medium-sized perforations have certainly a greater tendency to close up than the larger ones; but there is nothing certain about this; all depends on the vitality of the tissues of the tympanic membrane.

It has seemed to us that perforations situated in an atrophic tympanic membrane, as also the marginal ones ordinarily limited to the postero-inferior segment, have most difficulty in healing.

(2) *The tympanic wound becomes infected.*

This infection arises from three causes:—First, at the time of the traumatism, débris of earth and gravel have been carried with the air into the auditory meatus as far as the tympanic membrane; or else the patient has been buried, thrown to the ground and rises again covered with dirt; spontaneous efforts to clean the meatus have only had the effect of pushing the débris further in.

Further, the patient has blown his nose, perhaps violently, with both nostrils closed. A little mucus from the Eustachian tube or naso-pharynx has been driven into the tympanum and has infected it.

But the greatest cause of infection exists in *medicated lotions and inopportune instillations of "ear-drops."* On arriving at the aid-posts, all the wounded who suffer from bleeding from the ear run the risk of having their ears syringed; this proceeding carries into the tympanum débris of cerumen mixed with mud, and leaves at the bottom of the meatus a drop of dirty water, inevitably causing

infection. Some who are more moderate know that syringing is harmful, but they cannot resist the temptation to instil glycerine in some form, carbolised or otherwise. This creates at the bottom of the meatus a humid condition favourable to infection. Do not we know that certain cases of suppurative otitis get well only after the suppression of glycerine instillations, and after the use of absolutely dry dressings ?

Suppuration which arises in this way appears in three, four, five, or, it may be, eight days after the injury, sometimes later, according to how early the infection has taken place.

Other lesions of the tympanic membrane.—Rupture of the tympanic membrane is ordinarily the only ascertainable lesion. Do there exist, as some think, dislocations or ruptures of the ossicles ? We have never seen evidence of such.

Tympanic lesions may be unilateral or bilateral, but in the latter case the two ears are not usually affected in the same degree.

Symptoms.—(1) **Aseptic form.**—Two signs direct attention to the ear—otorrhagia and deafness.

Otorrhagia is generally slight ; a few drops appear in the auditory meatus. This hæmorrhage may even be absent. As in injury of the limbs, the violence of the rupture brings about hæmostasis of some sort ; a little drop of effused blood remains adherent to the tympanic membrane.

The *deafness* is equally variable ; it appears at the commencement or a few days later ; it varies from simple dullness of hearing to complete deafness, with subjective noises (buzzings and whistlings) ; but these severe symptoms arise from concomitant labyrinthine lesions.

Objective examination.—At first, a small interstitial hæmorrhage of the tympanic membrane or, more often, a little coagulated blood in the depths of the meatus, more or less hiding a traumatic perforation of the tympanic membrane, is observed.

We will not dwell on those characteristics which we already know.

A punctiform perforation is revealed by Valsalva's test; a bent probe will penetrate the tympanic ring in cases of marginal openings. All other perforations can be recognised at the first glance; the pale gray mucous membrane of the typanum can be seen through them. The ossicles are intact.

This complete otoscopic examination is only possible after spontaneous breaking down of the clot which must be treated with respect so as to avoid a traumatism which is always harmful.

Examination of the hearing.—The deafness varies considerably according as the internal ear has escaped or, on the contrary, has been concussed by the same shock. These concussions form the subject of a special chapter and need not delay us here.

A simple perforation of the tympanic membrane may cause either a hardly perceptible deafness or, on the contrary, a marked one; if very small, it produces scarcely any weakening of the hearing power, but it would be very inexact to say that the hardness of hearing is in proportion to the extent of the loss of substance, and otoscopic examination cannot show the extent of the functional disturbances.

However, according to Maurice, perforations situated opposite the fenestra rotunda would give rise to a greater amount of deafness, for the following reason: an intact membrane transmits the sonorous

vibrations to the fenestra ovalis; the liquid in the labyrinth is driven back and, being incompressible, drives back in its turn the membrane of the fenestra rotunda; if the latter is rigid, the endolymph will be rendered immobile and the organ of Corti will not be set in vibration. Let us suppose there is a tympanic perforation situated opposite the fenestra rotunda; the sonorous vibration which knocks against the fenestra ovalis strikes simultaneously and directly the fenestra rotunda, and the labyrinthine fluid becomes immobile.

In fact, we have, a long time ago, seen patients with large posterior and inferior perforations, whose hearing was suddenly and *enormously* increased by introducing a pellet of cotton wool at the level of the fenestra rotunda. Thus the excellent but too rare good results of the use of artificial drums are to be explained.

It is unnecessary to dwell on the responses to the various hearing tests—preservation of bone conduction, diminution of air conduction, lateralisation of Weber to the affected side.

It may seem surprising that a traumatism violent enough to cause the tympanic membrane to burst most often leaves the labyrinthine function intact; rupture of the tympanic membrane ordinarily saves the internal ear.

This result is perhaps brought about by a double mechanism. In the first place, rupture of the elastic fibres of the middle layer of the tympanic membrane deadens the violence of the shock at the same time that it diminishes the extent of the surface of reception. Next, the projected column of air, penetrating through this perforation into the tympanum, produces an *actual*

damming-up of the labyrinthine fluid. The pressure which it exerts on the fenestra rotunda opposes the displacement on the outside of the fenestral membrane, and consequently check the driving-in of the stapes whether alone or combined with that of the tympanic membrane.

(2) **Suppurative form.**—Suppuration shows itself some days after the injury by pain in the ear and purulent discharge.

The pain is ordinarily much less severe than in acute idiopathic otitis; the tympanic perforation, preceding the suppuration, prevents the accumulation of pus in the drum and suppresses the distension. The actual pain is chiefly caused by retention; it is intense if the perforation is too small; there is simply a sensation of heat in the ear if the perforation is large; sometimes the dull pain of latent mastoiditis, with feverishness and constitutional disturbances, is present, indicating that the mastoid is involved.

The *purulent discharge* is also variable in quantity, sometimes reduced to a few drops of serous liquid, while in other cases it is very profuse and decidedly purulent.

Objective examination, after the meatus has been cleansed, reveals a perforation of the tympanic membrane which is red and tumefied as is also the visible aural mucous membrane. In a few old-standing cases this mucous membrane appears granular, polypoid and sometimes even ulcerated, and the probe comes in contact with superficial osteitic lesions.

The *deafness* is much more marked than in the aseptic form and, above all, more lasting on account of the adhesions following the suppuration.

The course of traumatic suppurative median otitis,

with the exception of the slight cases which become cured in a few days, has appeared to us to have a much more gloomy prognosis than that of acute idiopathic otitis. The latter, caused by the development on the healthy aural mucous membrane of infective germs which have already invaded the organism and which had come from a neighbouring region, has generally a cyclical course. Apart from the rare cases where, owing to feebleness of the organism or from the extreme virulence of the pathogenic agents, deep lesions are produced which aggravate the prognosis, the suppuration ordinarily presents a spontaneous tendency to dry up; it is only necessary to prevent retention and stagnation of the pus as well as secondary infection. Infection of the mucous membrane of the tympanum has a course similar to that of the nose, namely, serous, purulent, muco-purulent discharge, then dryness.

The course of an acute traumatic otitis is quite different. The abrasion of the tissues, the possible presence in the tympanum or the depths of the meatus of débris of earth acting as a foreign body, the virulence and multiplicity of the infective germs, until then foreign to the organism, all explain the profuseness and persistence of the suppuration and the absence of any tendency to spontaneous cessation of the discharge.

The war has brought to our notice, in connection with the ear as with the limbs, infections of a severity unknown in time of peace.

It is difficult to fix an average duration for traumatic suppurative otitis. Rarely limited to a few days in cases where the infection of the tympanic wound is of Eustachian tubal origin, the duration too often

runs into weeks and months; healing is frequently imperfect with persistence of the perforation, cicatricial bands and the possible recurrence of suppuration.

Acute traumatic otitis is sometimes complicated by acute mastoiditis. Out of 373 cases of traumatic otitis, we have observed it 12 times. Most of them came from the Front almost simultaneously, in two or three batches; was this a coincidence of some special defect in treatment or of an influenzal surrounding?

The course of the mastoid lesions shows nothing unusual. They heal normally, after the trephining, whilst the ear often does not dry up. Is this persistence of the otitis to be attributed to incomplete or to too tardy intervention? Yes, in many cases; but that is not the only reason. The persistence of a tympanic discharge depends fairly often on a deep-seated affection of the mucous membrane or on the presence in the depths of the tympanum of microscopic foreign bodies. More often these cases of otitis have appeared to us difficult to cure even after the mastoid operation, and even when this had been carried out by different operators, with among them some of the highest reputation.

Prognosis.—The prognosis of the aseptic forms is relatively favourable. Anatomical *restitutio ad integrum* depends on the size of the perforation and the vitality of the tissues. As for the hearing, it is influenced by the extent and the situation of the perforation, by causes which escape our notice and above all by the state of the labyrinth.

The suppurative forms have a more gloomy prognosis. We have not come across any which

have been the cause of death by immediate complications, but the persistence of an obstinate otorrhœa is not without danger. The prognosis as to function is always mediocre, even if the suppuration ceases and the perforation becomes cicatrised; the hearing remains poor on account of the cicatricial bands and the adhesions which have formed.

Diagnosis.—A recent aseptic perforation is recognised by the presence of the clot, the extravasation of blood from the membrane and the red margin round the orifice.

A diagnosis made later on is much more difficult; a whitish tract, an atrophic zone, bear witness to cicatrisation of an old perforation, but there is nothing to show its traumatic nature. If there is a persistent opening, of a serrated appearance with notched edges, soundness of the tympanic lining is evidence in favour of trauma, but this does not afford absolute certainty.

Only the former history remains to establish the accidental origin of the suppurative forms, and its evidence must be taken with reserve.

Treatment

The aseptic form.—Immediate treatment.—The line of conduct to be followed when a recent rupture of the tympanic membrane is present, may be summed up in two words—complete *abstention.*

The doctor and his assistants should absolutely avoid all moist treatment of the ear; they should practise no syringing, no instillation. If absolutely necessary, the external auditory meatus may be cleansed with dry cotton-wool, care being taken not

to drive any foreign body into the deeper part. A simple plug of cotton-wool or a dry dressing, thicker when there is profuse hæmorrhage, should be used to stop up the auditory meatus whilst waiting for the transference of the patient to a special clinic.

There, the otologist, under the control of the forehead mirror, proceeds with a very detailed cleansing of the meatus by the dry method or with slightly moistened cotton-wool. He will be careful not to injure the tympanic membrane. He will conclude by introducing a strip of aseptic gauze.

With these precautions, the hospital treatment required is of *very short duration.*

Later treatment. — *Tympanic prothesis.* — A dry unilateral perforation of the tympanic membrane, with preservation of the function of the other ear, does not require any further treatment than care to prevent the water used for washing purposes or the bath entering the middle ear. But we too often come across the association of a traumatic median otitis of one side with extreme labyrinthine deafness, due to concussion or some other cause, of the opposite side. The functional incapacity may, therefore, be considerable. We are powerless with regard to the labyrinthine deafness; we can sometimes greatly ameliorate the deafness of the ear which is simply perforated, provided that the functions of the cochlea are preserved, and the importance of such an amelioration is great; we look for it in the results of prothesis of the tympanic membrane; it must be confessed that successful results are rare, but they are sometimes so decided that this tympanic prothesis should always be tried, provided the ear is absolutely dry.

A description of the various forms of artificial

drums will be found in classic treatises. We shall confine ourselves to describing the technique adopted by one of us (Bourgeois) for many years. It is extremely simple.

As material for an artificial membrane, a thin layer is cut from the very fine indiarubber ordinarily used by electricians. Its form and its dimensions are such that it will amply cover up the loss of substance in every direction; it is sterilised by boiling, as is also, at the same time, a concentrated solution of tragacanth. After cooling, the thin fragment of gum-elastic is plastered over on one side with the solution of gum, seized with fine bent forceps and applied to the tympanic membrane; a bent probe causes it to slide on to the membrane till it is placed in the right position. The patient makes a "Valsalva" movement which drives the tympanic membrane against the indiarubber, and testifies as to the absence of any escape of air. It is again put in position and the patient is asked not to blow his nose for several hours.

The results of this practice are not always the same.

Some patients complain of a disagreeable resonance, of noises or a feeling of foreign body, and they will not tolerate the artificial membrane. Others derive no benefit from it; in others again it produces an oozing from the ear, which causes the indiarubber to become detached and shows that it is not tolerated. These are the unfavourable cases.

Other deaf subjects, unhappily too rare, find an increase in their hearing from the shouted voice on contact to the spoken voice at one or two metres;

they will not live without their artificial drum. They should be seen every month at first, then, later, three or four times a year.

Again, in certain others, the success is complete in that the presence of the indiarubber stimulates the vitality of the tympanic membrane so that the perforation may be seen to close up of itself and thus render the artificial drum henceforth unnecessary.

The suppurative form.—The treatment of traumatic suppurations differs entirely from that of acute idiopathic otitis. Asepsis and satisfactory drainage are sufficient to cure the latter, while for traumatic otitis, at least in the severe forms, *antisepsis cannot be dispensed with.*

During the first few days the meatus is full of thick, coloured, often fetid pus. Our first care is to cleanse the region; the hair should be cut with scissors, the meatus plugged with non-absorbent cotton-wool, and the auricle and neighbouring parts washed first with soap and then with alcohol.

The meatus is cleansed from pus by syringing with Hartmann's cannula which the otologist himself guides under the control of the forehead mirror; he will not forget to direct the stream on to the floor of the tympanum, thus driving out any foreign bodies that may be present. An antiseptic should be added to the tepid water: peroxide of hydrogen or, by preference, Labarraque's solution in the strength of 5 per cent. Dakin's Liquid has given us equally good results. After drying, a small plug of aseptic gauze is introduced into the meatus, and finally a thick dry occlusive dressing is applied.

This treatment should be renewed, according to need, once or twice a day.

There should be no hesitation in performing a paracentesis at the site of election, if the perforation is small and retention certain.

Later on, when the pus becomes clear, the syringing should be followed by an application of chloride of zinc (1 in 50) or by an ear-bath of a solution of nitrate of silver (1 in 100). The granulations should be cauterised.

Later on still, when the pus becomes less profuse, the syringing should be stopped and, according to the case, one or two baths of nitrate of silver (1 in 30), instillations of boricated alcohol and insufflations of boracic acid powder used. The plugging should be dry.

If mastoiditis supervenes during the course of the disease, the ordinary treatment is employed, that is to say, the classic mastoid operation; while the treatment of the lesions of the tympanum and tympanic membrane should be continued as we have just indicated.

CHAPTER VI

WOUNDS IN THE AURICULO-MASTOID REGION

Etiology.—**Frequency.**—These injuries are rare. Out of 700 cases of war ear-lesions observed at the Limoges Centre, we found only 12 auriculo-mastoid wounds, namely, 1·6 per cent.; we may add to these 4 cases recently observed elsewhere. Lannois and Chavanne have only noted 38 out of a total of 1,000 cases of war deafness, namely, 3·8 per cent. No doubt a certain number escape our notice; these wounds are treated at once in the general surgical clinics; but the otologist is often called in to attend to the secondary deafness. The extreme rarity of these cases depends partly on their seriousness; such lesions of the lower part of the skull must cause death on the battlefield, and those which come before us are in the main only the milder forms. Out of 336 wounded (who were unable to be moved) treated lately in our ambulance (Bourgeois), there were 31 with wounds of the skull, of which only one had involvement of the mastoid region.

The determining cause is always a solid projectile, a bullet from a gun or shrapnel, splinters from a shell or grenade, some small and multiple, others large and single.

The projectile strikes the region of the ear in one of three directions—perpendicular, parallel or oblique ; hence there is a certain amount of diversity in the resulting lesions.

Pathological anatomy. — Auriculo-mastoid injuries caused by weapons of warfare are somewhat different from those observed in civil practice. In the latter, usually the result of attempts at suicide, the weapon is almost invariably applied at the level of the external auditory meatus ; the latter regulates to a certain extent the direction of the feebly driven projectile and the situation of the lesions, by its anatomical configuration and mode of resistance. Le Mée[1] has made a very complete study of this subject in his thesis.

The great force of the projectile of warfare, the variability of the direction and point of penetration, give rise to disorders which defy all definite laws.

However, we have been able to distinguish four varieties among the cases which we have observed :—

(1) *Tangential wounds*, in which the projectile has only just grazed the surface of the mastoid.

(2) *Plunging wounds ;* these arise from a fragment of a shell, generally of considerable size, which approaches the mastoid region directly or obliquely ; it drives before it the superficial layers, the resistance of which weakens its power of penetration.

(3) *Penetrating wounds ;* the projectile enters deeply into the tissues and remains embedded in the mastoid process or the middle ear.

(4) *Perforating wounds ;* a bullet coming at full speed penetrates the auriculo-mastoid region, traverses it more or less deeply, and emerges close by or at a

1 LE MÉE, *Des coups de feu dans l'oreille*, Thèse de Paris, 1910.

distance, it may be even through the opposite auricular region. Sometimes the projectile lodges in an adjoining region—the brain, the nape of the neck, or the bony framework of the face.

The lesions caused by these violent traumatisms are seldom limited to the mastoid process.

The auricle and the membranous auditory meatus, which protect its anterior and exterior surfaces, may be struck in the first place, cut off or lacerated.

The mastoid process is merely grazed in tangential wounds ; the soft parts are injured, but on the external cortex there is scarcely even a simple groove or small fissure to be found. This, however, may extend fairly deeply ; in a case of this kind we observed actual hæmorrhage of the tympanum, at the level of the postero-superior quadrant of the membrane.

The mastoid process may be totally or partially broken down by the projectile which remains embedded or continues its course. The cells, the antrum, the aqueduct of Fallopius are opened ; the internal and external cortex are reduced to splintered fragments which project into the depth of the wound.

Fracture in the mastoid region includes that of the osseous auditory meatus and the peri-tympanic ring ; the tympanic membrane is ruptured, the ossicles dislocated and the tympanum opened. The roof of the antrum and the attic, and the external wall of the labyrinth may be destroyed or fissured by the projectile itself or the spreading of a fissure from the mastoid fracture. In the latter case, according to the experience of Le Mée, irradiation of the fracture takes place above towards the temporal bone, below towards the tympanic bone and the tympanum, and inwards towards the internal ear, tending to isolate

the mastoid process and the semi-circular canals on the one hand, and the petrous bone and cochlea on the other.

Finally, the lesions may extend beyond the limits of the organ of hearing; the meninges and brain, the intra- and extra-petrous branches of the facial nerve may be affected. We have not ourselves observed, nor seen mentioned by others, lesions of the carotid or sinusal vessels.

Course.—These wounds very often become infected and suppurate profusely, especially when they are accompanied by opening of the tympanum. The mastoid is infected step by step through the intercellular communications, as in the case of an actual mastoiditis.

The anfractuosity of the wound and the presence of loose splinters forming a foreign body, cause the suppuration to have no tendency to spontaneous recovery. Cicatrisation takes place partially; one or two fistulæ may persist to show that the suppuration is still present; it indicates a menace of serious complications.

Symptoms.—The wounded man loses consciousness at the moment of being wounded. He is still more or less in a condition of shock when he arrives at the ambulance. He bleeds profusely from the affected region and sometimes presents a complete or partial facial paralysis of the same side. Further, he is generally completely deaf in the injured ear; giddiness, vomiting, spontaneous nystagmus, indicating a severe affection of the anterior and posterior labyrinths, may even be observed as well.

An objective examination of the wound does not reveal the exact extent of the lesions; those of the

soft parts, of the auricle and the membranous auditory meatus are evident; the existence of a mastoid fracture can be easily discovered by palpation. The blind introduction of a probe into the depth of the wound is a dangerous and useless proceeding; undoubtedly it would give some information as to the presence or the situation of an embedded projectile or of loose splinters of bone, but the dura mater or the lateral sinus may be exposed and there would be a risk of injuring them if the patient made the slightest movement.

Otoscopic examination is not always possible; fracture of the meatus and profuse bleeding may stand in the way; if not, the tympanic membrane will be seen either intact or ruptured, with or without hæmorrhage of the tympanum.

The appearance of the wound is quite different when the wounded man arrives some days or some weeks later at the otological centre. Cicatrisation will have already commenced, and the *auditory meatus is very often stenosed* (four times out of twelve). The wound no longer bleeds; it suppurates, especially if the tympanum has been opened and the early necessary operation has been deferred or incompletely performed. The integuments are infiltrated and the fetid pus empties itself externally by one or more fistular orifices which have granular edges and are situated in the meatus or on the external surface of the mastoid.

The wounded man complains sometimes of great pain and headache localised in the temporo-occipital region of the affected side.

Examination of the hearing gives varying results; a lesion limited to the mastoid region produces no

defect of hearing-power, such an event, however, being rare; likewise fairly severe dulness of hearing, due to obstruction of the auditory meatus or to lesions of the tympanum, affecting the aerial transmission of sounds, with preservation of bone-conduction and lateralisation of Weber to the affected side, is an equally rare event; in general, that is to say in the great majority of cases, the labyrinth is affected, the ear is totally deaf and there is vertigo; these functional disturbances indicate the labyrinthine concussion from a blow on the cranium, which we shall study in the following chapter.

The general condition is good, unless there is retention of pus or an intra-cranial complication.

Complications. — **Facial paralysis.** — Facial paralysis is the most frequent complication; it most often appears at the time of the mastoid trauma. According to our observations (3 cases), and those of Moure (7 cases) published in the *Presse Médicale*,[1] the facial nerve is nearly always affected in its intra-petrous portion (9 cases out of 10). It becomes compressed, lacerated, or cut through partially or totally by splinters of bone.

Facial paralysis is most often complete, involving at the same time the superior and inferior branches of the facial nerve; it may be partial, in which case it is susceptible of amelioration by appropriate treatment according to the degree of damage of the nerve.

Temporo-maxillary ankylosis.—We have seen this ankylosis twice; it results from different lesions:—

Direct injury of the joint by the projectile or a fragment of fractured tympanic bone.

1 MOURE, *Paralysies faciales de la guerre*, "Presse Médicale," April 13, 1916.

Inflammatory reactions of the synovial membrane, caused by the neighbouring suppuration.

Retractile cicatrisation of the peripheral tissues.

Reflex contraction of the masseter muscles, on account of the pain round the ear which is caused by the movements.

Meningeal and cranial complications.—Personally we have seen none of these. We have noted in two of our operation cases, exposure in one of the dura-mater over a surface of 1 square centimetre, and in another rupture of the dura-mater by a splinter of bone; the meningeal orifice was covered over by the inferior surface of the temporal lobe. These two wounded men recovered without any signs of infection.

There must undoubtedly exist less fortunate cases, where the rupture of the meninges is followed, as in any other fracture of the skull, by infective complications; these may arise early or late.

In the first case there is acute meningitis or diffuse meningo-encephalitis, which rapidly ends fatally. In the second, the lesions have a tendency to become localised; they may vary from an extra-dural abscess, with a favourable prognosis, to a deep-seated abscess of the cerebrum or cerebellum, necessarily a very serious condition.

Lateral sinus and internal carotid.—The lateral sinus and the carotid may be opened at the same time as the injury, primary fatal hæmorrhage resulting before any intervention is possible. Later on the sinus may be affected by the spreading of the infection, causing thrombo-phlebitis or possibly septicæmia. We have never observed such a case.

Diagnosis.—The diagnosis of an auriculo-mastoid

wound is, so to speak, evident. The difficulty commences when we try to determine the extent of the deep lesions. Clinical examination does not always give the necessary information; it must be completed by X-ray examination.

Radioscopy of the mastoid region is insufficient; it merely discloses the more marked injuries and large projectiles.

Radiography is indispensable; it should be carried out in the oblique position. In the case of an embedded foreign body, we must have resort to the localiser, and a Hirtz or Marion-Danion compass will often be of the greatest service in the course of an operation.

In order to trace a meningeal, cerebral or cerebellar complication, we employ the usual means for examining these organs in otorrhœic subjects, namely, lumbar puncture, the investigation of the equilibrium in standing upright and walking, as also Barany's reflexes.

Prognosis.—An exact prognosis is impossible to establish, as we have no statistics as to the immediate mortality.

The prognosis *ad vitam* of auriculo-mastoid injuries observed a certain time after the trauma, seems good; it depends above all on the condition of the meninges and appropriate treatment.

As to the auditory function, it is unfortunately very often affected, total labyrinthine deafness being generally permanent.

Treatment

General indications.—Auriculo-mastoid wounds with fracture of the mastoid process, call for surgical

treatment; this should be carried out early, but is not necessarily of extreme urgency unless a profuse hæmorrhage demands immediate hæmostasis.

The early treatment has for its aim exploration of the seat of the fracture, the removal of any cause of compression likely to injure an important organ, the prevention of infection by surgical cleansing of the wound, and, finally, the re-establishment or modification of the anatomical condition of the soft parts of the ear, in view of its functions, in particular the *avoidance of stenosis of the meatus.*

All serious operations on the ear or its neighbouring parts require special instruments and a knowledge of the particular technical proceedings on the part of the surgeon.

Immediate treatment.—At the aid-post or the ambulance, cleansing of the wound and its edges in such a way as to avoid infection is all that is required; the hair should be cut, the auriculo-mastoid region shaved and then treated with ether or tincture of iodine.

As the tympanum may be opened by a tympanic rupture or fracture of the meatus, great care must be taken to avoid the entrance of any liquid into the middle ear; there should be *no syringing or instillations of drops;* a simple dry dressing should cover the wound while awaiting rapid transference of the wounded man to a special hospital at the front, where the necessary surgical intervention will be carried out.

Early operative treatment.—**Tangential wounds.**—It is sufficient to treat the soft parts which have been injured by means of disinfection, removal of dead tissues and sutures. We know what to

do for lesions of the auricle and the membranous meatus.

We need not occupy ourselves here with chipping or fissure of the external cortex; it heals spontaneously. We should keep an eye on the condition of the tympanum, and the course of any slight intra-tympanic hæmorrhage which may become absorbed without suppuration; should suppuration take place, the treatment should be that for an acute traumatic median otitis, namely, paracentesis and even mastoid trephining if the infection extends to the mastoid process.

Wounds with fracture of the mastoid process.—This is a variety of fracture of the cranium; surgical exploration is called for.

The complex anatomical nature of the region, the close proximity of vital organs, the position of which is not absolutely fixed in relation to the external landmarks, call for prudent and methodical exploration. The variability of the seat and extent of the lesions, stands in the way of operating according to a technical rule; the surgeon must, however, be guided by some general principles.

(1) The exploration to be complete must not be limited to the superficial layers; the mastoid trephining must be extensive and must allow of examination of the deeply-seated organs.

(2) The surgeon must not, at the commencement of his operation, be guided exclusively by the lesions.

He will take the bearings for his exploration in relation to an exact point which will all the time indicate to him the situation of the organs to be avoided. The fundamental mark for the mastoid *is the antrum*, a veritable cross-road which leads in

front towards the tympanum and external auditory meatus, behind and below towards the facial nerve, inwardly towards the labyrinth, above towards the meninges and cerebrum, behind towards the cerebellum and lateral sinus. *The exploration and opening of the antrum constitute the first stage of the operation.*

(3) At the first onset to keep away as much as possible from the injured area, so as not to mobilise or loosen the obstructing fragments until after having made a sufficient lateral opening to avoid injury of the deeply seated organs.

We shall then conduct the operation as follows :—

(*a*) *Trephining the antrum.*

The usual retro-auricular incision without regard to the position of the cutaneous orifice of penetration of the projectile.

Exploration of the antrum :—

At the site of election if the focus of the fracture is not found at this level.

Lower down at the level of the tip, if the fracture of the bones occupies the angle formed by the supra-mastoid ridge and the posterior margin of the auditory meatus. We return towards the antrum by following in its depths Lombard's cellular inter-sinuso-facial tract, and by resecting the external cortex with a gouge forceps.

(*b*) *Gradual widening* of the orifice of trepanation, by steering towards the *focus of the fracture which we attack from its periphery.*

Ablation of the splinters of bone, of the projectile itself and of the bone beyond the traumatised zone.

The operation-cavity must be easily visible in its whole extent, once the operation is completed ; the surgeon will explore it with the eye and the probe

in order to be sure that no mobile fragment remains on any of the walls, that there may be no zone of retention or stagnation during the healing and that the drainage may be efficacious. He will pay special attention to the posterior margin of the bony meatus, which will be left in its place if normal, and resected if fractured. We finish up by suturing the upper two-thirds of the wound; if desired, a drainage-tube may be placed in the lower angle of the wound; it must only be left *in situ* for a few days; no plugging should be employed; rapid healing without suppuration will take place if we are wise enough to avoid any exploration, applications and later interference with the cavity.

This technique is reserved for those cases—rare, it is true—where the injury is purely a mastoid one, without laceration of the auditory meatus. When this has taken place, the operation is concluded in a different manner, namely, as in the last part of a petro-mastoid opening, either by resecting the posterior wall by cutting out of it a large posterior flap, according to the shape of the mastoid cavity and the preferences of each operator To finish, total suture of the retro-auricular incision will be carried out; the dressing should be done through the meatus; it consists of plugging so as to allow of drainage and the preservation of a large meatus. The wound will heal by filling up and epidermisation.

Infected wounds. — *Traumatic mastoiditis with integrity of the meatus and tympanum.*—Trephining a fractured and infected mastoid process follows the same principles as the treatment of an ordinary mastoiditis. The infection is supposed to have reached all the cells by gradual stages; the mastoid

process must be opened from above downwards after total resection of the external cortex and with exposure of the aforesaid aberrant cells. To confine ourselves to the obvious apparent lesions, to open the antrum at its inferior part, to neglect the deep cells of the tip or the retro-facial ones, or again the postero-superior, is to condemn the wounded man to the formation of fistulas and to repeated operations; the experiment must not be made.

It was a good thing when we gave up plugging mastoid cavities; we suture their upper part, more or less completely, and employ simple dressings.

Traumatic mastoiditis with laceration of the membranous meatus and integrity of the tympanum.—Extensive trephining, as above stated, partial resection of the osseous meatus, resection of the posterior wall of the membranous meatus. Total retro-auricular suture. Dressings through the meatus.

Traumatic mastoiditis with traumatic median otitis.—The hearing is generally permanently damaged; there should be no hesitation about practising at the first onset a classical petro-mastoid opening, unless perhaps the aural lesions appear to be only very slight. The mastoid operation is nearly always called for.

Treatment of complications.—**Facial paralysis.**—We shall only concern ourselves with the facial paralysis which is secondary to an intra-petrous lesion.

It is sometimes kept up by simple compression from a fragment of bone or perhaps an effusion of blood, sometimes by contusion of the nerve which may at the same time be partially lacerated, sometimes by section or even destruction along 1 cm. or more of

its course. Paralysis secondary to compression heals rapidly after the correct carrying out of a mastoid opening.

A nerve which has been simply contused or partially lacerated also shows, after the mastoid opening, signs of functional restoration which are of good omen.

Complete section, in which it is impossible to predict the anatomical relation of the two fragments, has a much more serious prognosis. Prof. Moure has proposed [1] systematic exposure of the nerve in the Fallopian canal, immediately above and behind the fenestra ovalis, after an extensive opening of the petro-mastoid region; he then follows it along its whole mastoid course, and if he finds it divided he sutures it. He has carried out this delicate operation several times; the results have seemed to him very encouraging; it will be very interesting to know the distant future histories of these cases.

Ankylosis of the maxilla.—We must never forget to watch the movements of the temporo-maxillary articulation. The slightest tendency to trismus calls urgently for early mobilisation, that is to say, gradual separation by means of suitably adapted mouth-props. Neglect of this part of the treatment dooms the patient to an extremely inconvenient infirmity.

Old-standing ankylosis is amenable to surgical treatment. Morestin gives the preference to Le Dentu's operation; we shall not describe it; we should be going outside our subject.

Injury of the lateral sinus.—Surgeons cannot have seen many injuries of the sinus; the wounded men die before reaching the operation hall; a

La Presse Médicale, 1916.

temporary spontaneous hæmostasis does not, however, appear impossible to us under certain conditions. Laceration of the vessel sometimes occurs in the course of trephining the mastoid process, particularly when the bone is splintered. The course of action should be the same in both cases. These venous hæmorrhages are very easily arrested by plugging. A wound of the lateral sinus is not dangerous on account of the hæmorrhage when this is treated in time, but on account of the liability to infection through the blood.

A hasty rough first dressing is effected immediately with gauze that serves to staunch the blood during the operation; the assistant holds this dressing *in situ;* the surgeon picks out a strip of aseptic or iodoform gauze; he takes hold of the end—which should be fairly narrow—with straight or bent forceps without teeth but slightly roughened; the assistant slowly raises the temporary dressing and the surgeon immediately places his gauze on the sinus—as much as possible on the sinus, not in the cavity; he packs it and above it he places another plug; he continues his operation towards the tip, towards the upper part, or towards the meatus, wherever he has to get to and where he finds access. The operation must be quickly brought to a close; an open sinus must not be allowed to remain exposed to the entrance of splinters of bone and an infected focus.

The exterior dressing must be changed the next day; on the following one all the strips which plug the mastoid cavity are removed, being gently loosened by means of peroxide of hydrogen. The strip in the sinus above remains *in situ.* The dressing is repeated each day. On the fourth day we begin to pull on the strip in the sinus, after detaching it, and

we cut away with scissors whatever part of it comes easily and without hæmorrhage. On the sixth day the whole of it can generally be removed in this way.

The temperature is taken regularly each day, note being made of the slightest rigor which would call for immediate removal of the strip of gauze in the sinus and its replacement.

We cannot here deal with thrombo-phlebitis of the lateral sinus and the consequent pyæmia, without getting beyond the limits of this work. We will refer the reader to the classical treatises on the subject.

Injuries of the dura-mater.—Exposure and even rupture of the dura-mater in a non-infected or early disinfected area, do not necessitate a very bad prognosis. Care should be taken not to mobilise the edges of a meningeal wound and thus to avoid breaking down the very useful adhesions; what is required above everything is to search for and remove all splinters of bone and all foreign bodies in the neighbourhood; death may supervene on account of a microscopic chip of bone slipping between the dura-mater and the roof of the antrum; we must, further, not be afraid to lay bare this membrane sufficiently to enable us to feel sure that nothing remains between it and the bone which it lines.

Suppurative meningitis and abscess of the brain must be treated according to the recognised methods; they may sometimes be cured, especially abscesses. The prognosis of diffuse encephalitis is, on the contrary, fatal.

THIRD PART

WAR DEAFNESS

CHAPTER VII

LABYRINTHINE CONCUSSION FROM DIRECT VIOLENCE TO THE CRANIUM

Labyrinthine deafness secondary to a blow on the cranium is well known to us from the study of fractures of the petrous bone ; the war has taught us nothing essential on this subject.

Etiology.—The shock may be due to a fall on the head or to a blow from a blunt instrument such as a stone or billet, as may take place on the falling-in of a dug-out or trench.

The usual cause, however, is a projectile—a bullet or splinter from a shell—striking the cranium perpendicularly or tangentially to its surface.

The degree of injury to the labyrinth depends on two conditions :—1st, the speed and size of the projectile ; 2nd, the spot at which it strikes the cranium or the framework of the face.

A blow on the mastoid region is the most formidable as regards the internal ear.

Lannois and Chavanne, in their statistics, report that out of 38 injuries of the mastoid region, the hearing was destroyed in 94 per cent. of cases—totally in 73 per cent., and partially in 21 per cent. Our own statistics (Bourgeois), which are registered as 23 cases of cranial injuries by projectiles of war, 15 of which were mastoid wounds, give us for this last variety 9 cases of total labyrinthine deafness, say 60 per cent., and 5 cases of partial deafness, 33 per cent., making a total of 93 per cent.

The projectile, though of the same force, is much less harmful when it strikes at some distance from the ear.

In injuries of the temporo-maxillary region, our statistics (three cases) give us one-third total deafness, one-third partial deafness.

With regard to other regions of the cranium, namely, occipital and temporo-parietal, injury to the labyrinth is again frequent (Chatelin); it is rarer in traumatisms of the frontal region (Lannois and Chavanne).

Finally, there seems to be no labyrinthine lesion when the projectile only involves the soft parts, particularly in wounds of the external auditory membranous meatus.

Pathological anatomy.—**Seat of the lesion.**—As a rule in cranial injuries from projectiles of war, the labyrinthine lesion is unilateral and on the same side as the injury; in only 2 cases out of 23 was it found to be bilateral but less marked on one side than the other.

The anterior (cochlear) labyrinth was alone affected, with total or partial unilateral deafness, ten times.

In five other cases the cochlea and the vestibular

apparatus were affected simultaneously—four exactly alike with total deafness and loss of excitability of the vestibular nerve, one with total deafness and hypo-excitability. Finally, in two cases there was an inverse dissociation, namely preservation of the anterior labyrinth with impairment of the posterior, total in one case and partial in the other.

Nature of the lesion.—The nature of the lesion very often escapes us for want of direct examinations, autopsies and histological researches.

According to pre-war writings, particularly those of Halphen [1] and Le Mée, three forms of pathological involvement may be observed :—

(*a*) Complete destruction of the internal ear by the projectile itself; this is rare, the labyrinth being deeply situated.

(*b*) Irradiation of a fracture of the mastoid process or the base of the skull to the osseous labyrinth. If the *fracture is macroscopic*, the perpendicular tract in the direction of the petrous bone involves the vestibule, the semi-circular canals, the cochlea and often the aqueduct of Fallopius. The membranous labyrinth is ruptured, filled with blood, the organ of Corti is destroyed and the facial nerve paralysed.

If the *fracture is microscopic*, its principal seat is at the level of the inter-fenestral region, the promontory and the beginning of the scala tympani. It is accompanied by profuse extra- and intra-labyrinthine hæmorrhage with impairment of the epithelium and nerve.

(*c*) Lesions of the membranous labyrinth without injury to the bone; "hæmorrhages into

[1] HALPHEN, *Lésions traumatiques de l'oreille interne.* Thèse, Paris, 1910.

the narrow canals, into the region of the fenestra rotunda and into the nerve trunks; fissure of the inferior part of the vestibule but preservation of the osseous capsule properly so called." The acoustic lesions are generally much more marked than the vestibular ones.

Course.—The fracture becomes consolidated; the hæmorrhage becomes absorbed; suppuration rarely takes place. Later on, Nager's chronic obliterating internal otitis shows itself, "the labyrinth is invaded by fibro-osseous tissue; the membranous vestibule is out of shape and unrecognisable; the auditory cells can no longer be differentiated; the cochlear nerve degenerates."

Pathogenesis.—When the existence of a fracture of the osseous capsule of the labyrinth can be made out macroscopically, the mechanism of the labyrinthine lesion is evident, namely that it is the result of direct violence from a projectile against the labyrinthine wall or of the irradiation of a fracture of the vault to the base of the skull.

The problem commences, however, when no macroscopic lesion of the osseous capsule is to be found.

The existence of a deeply-seated lesion in the membranous labyrinth cannot be doubted when all the clinical signs of definite organic labyrinthine deafness are present. Can this membranous lesion exist without an osseous lesion? Le Mée does not believe so. According to him the real cause of the membranous lesion is a microscopic fracture of the petrous bone; "it is that and not the concussion which gives rise to the labyrinthine hæmorrhage." This is also Toubert's opinion.

Lannois and Chavanne, without rejecting the

microscopic fracture theory, admit the possibility of labyrinthine concussion and membranous lesions without involvement of the bone :—" We must admit lesions of the organ of Corti analogous to ruptures of the choroid in wounded men in whom the projectiles have passed at some distance from the eye."

We believe, in regard to a microscopic fracture, that it may be the chief cause of the labyrinthine hæmorrhages after blows on the cranium from blunt slowly-moving objects, the action of which is prolonged in some way ; the bone gives way under the slow continuous pressure ; the depressions are disconnected.

But we must acknowledge the possibility of membranous lesions, either alone or associated with an osseous lesion. It seems to us that a projectile moving at great speed and with an extremely short action on the cranium must, on account of the rapid shock, bring about an intense vibratory movement which is transmitted by bone-conduction (as with a tuning-fork on the vertex) to the whole of the solid mass of the skull and extends to the labyrinthine liquid, the exaggerated displacement of which brings about rupture of the fragile endings of the nerve of hearing or of the fine capillaries.

Thus we have a labyrinthine deafness by the conduction of an exaggerated vibratory movement through the solid bone, just as occurs by air-conduction, as we shall see in the following chapter.

And if the first mode of transmission is really more perfect than the second, the seriousness of labyrinthine lesions in deafness caused by direct violence from a projectile on the cranium will be understood.

We must, however, admit that the absence of precise reports allows of hypotheses only.

Symptoms.—The wounded man usually becomes comatose immediately after the accident.

The labyrinthine symptoms may be made out some hours or days later, when consciousness has returned; they consist of total or partial deafness, subjective noises, vertigo, nausea, vomiting, spontaneous nystagmus, this combination of symptoms not being always complete.

The aurist only sees in the early stage, among these wounded men, those in whom the wound involves the auriculo-mastoid region; a preceding chapter has been devoted to this subject.

He examines the others later when the wound has become cicatrised and it is necessary to determine the nature and degree of the aural disturbances.

He first of all looks at the auricle; there is no visible lesion if the injury has not involved it; he then examines the injury produced by the missile in order to make out whether the bone has been touched.

A study of the hearing and the equilibrium reveals either an isolated or associated affection, total or partial, of the anterior and posterior labyrinths.

Auditory disturbances are by far the most frequent and the most important from the practical point of view. The lesions are happily unilateral in the great majority of cases. We have observed two cases of bilateral deafness (total on the right side and partial on the left) which had been produced by a bullet entering by the left temporo-maxillary region, its exit being at the level of the ascending branch of the right inferior maxilla.

Unilateral deafness is more often total than partial, nine times against seven (Bourgeois); by total

deafness is to be understood the absence of all auditory perception; concussion by direct violence differs in this respect from that from explosion where the abolition of the function is generally less complete. In the former the affected ear hears no sound; if such does not appear to be the case it is because in reality the hearing of the other ear has not been eliminated; this question will be considered in detail in the chapter on medical reports in connection with the erroneous perception of sharp sounds by the deaf ear, with also the "false" negative Rinne of Lermoyez and Hautant.

In the type described as partial deafness, the dulness of hearing has always appeared to us to be marked, the whispered voice being generally perceived only on contact. The different hearing tests bear witness to the labyrinthine origin of the lesion. In order to avoid useless repetition, we shall ask the reader to refer to the following chapter and to the one on medical reports.

Marked symptoms of disturbance of equilibration are frequent enough during the first days following the injury; they become less later on; certain injured men, however, complain of vertiginous symptoms when examined for medical report; they show a certain hesitation on walking, which becomes more apparent when the eyes are closed; there may also be noted a tendency to lean laterally towards the affected side or to fall backwards when in Romberg's position.

The vestibular tests furnish some interesting information; they show complete loss of excitability of the semi-circular canals to irrigation with cold water, or a marked hypo-excitability. The galvanic

current passed from one ear to the other shows either loss of vestibular excitability, hypo-excitability or an anomalous sense of balance, there being a tendency to fall backwards or to the side of the affected ear, whatever be the direction of the current.

Course. Prognosis.—Our previous knowledge concerning fractures of the petrous bone does not hold out any hope as to the future of these total deafnesses. They are incurable. Certain partial deafnesses are susceptible of some amelioration. We do not as yet possess any exact data on this point. The equilibrial disturbances disappear in the long run, even when the tests show a persistence of the loss of vestibular excitability; the opposite internal ear exercises a compensatory function; all the same, for some time sudden movements of the head may readily provoke dizziness; this, however, is of no importance; the vertiginous symptoms "generally decrease by degrees and finish by disappearing completely in less than a year after the injury" (Chatelin).

Diagnosis.—A man receives a violent blow on the head; he becomes deaf after it: it is not difficult to establish a diagnosis of labyrinthine concussion.

A much more difficult question arises in connection with the many with wounds of the skull who complain of vertigo and giddiness and who are referred to us in order that we may find out if these symptoms are the result of an aural lesion. For them a careful examination of the two functions of the internal ear is required.

The ascertainment of normal vestibular reactions implies that the labyrinths are unaffected.

The existence of a diminution of the perception of sounds by bone-conduction associated with hypo-

excitability of the semi-circular canals confirms the diagnosis of labyrinthine concussion, and the same may be said of a decided unilateral hypo-excitability even if unaccompanied by deafness.

But can it be said that the vertigo is certainly of aural origin when merely an anomaly, more or less pronounced, of the vestibular reflexes of the two sides is ascertainable? We do not believe so. These patients present, in addition, undeniable nervous lesions, and we do not know in which part of the reflex arc the cause of the observed phenomena is situated. The detection of these disturbances is equally interesting for the purpose of corroborating purely subjective phenomena. We must not forget, before deciding, that vestibular excitability varies greatly in different subjects, independently of any morbid condition.

The symptomatology of cerebellar and labyrinthine affections is similar in many points; the same injury may involve one or other organ or the two together. The result is that in the presence of certain injuries with equilibrial disturbances we have to ask ourselves whether the lesion is labyrinthine, cerebellar or a combination of the two; the cerebellum may suffer directly from an injury to the occipital region; it may be contused by a *contre-coup* from a blow on the vertex; either traumatism is equally capable of provoking labyrinthine concussion.

The labyrinth is alone affected.—The hearing is then generally diminished or abolished. The objective disturbances in walking are relatively less accentuated than the vertiginous sensations. The patient staggers on walking and he separates his legs to enlarge his base of support. He often veers to one side, namely

towards the affected one. The same lateral swaying is observed when he is in the upright position, standing on both feet or on one alone, or he may tend to fall backwards.

These disturbances are wanting in the milder cases, but they become more apparent if the eyes are closed. The sensation of falling is modified by the position of the head; if a man who has a tendency to fall towards the left has his head turned 90 degrees towards that side, he will have an inclination to fall backwards.

The rotation and caloric tests show hypo-excitability or inexcitability of the semi-circular canals, that is to say, nystagmus cannot be induced, or it takes long to appear and disappears quickly; at the same time the deviation of the limbs and the trunk, the direction of which is opposite to that of the nystagmus,[1] is less marked or is totally absent.

Babinski's galvanic test gives the results previously mentioned.

The cerebellum is alone affected.—The hearing is normal. The vertiginous symptoms are relatively less than the objective disturbances of co-ordination. These latter should be sought for in the upper and lower limbs[2]; a study should be made of the equilibrium during walking and in standing upright, of the sudden fall of a single part, disorderly movements, adiadokokinesis, asynergy, impairment of writing and speech, all of which symptoms have been minutely described by Babinski. Closing the eyes does not increase the loss of equilibration. Romberg's sign

[1] See page 1001

[2] See CHATELIN and DE MARTEL, *Blessures du crâne et du cerveau* (Collection Horizon), p. 140 and following pages.

is negative. Variations in the position of the head do not modify the sensation of falling.

Barany's nystagmic reflexes are normal, but—this is an important point—excitation of the vestibule no longer produces the movements of deviation of the limbs; for Barany has shown that this deviation is brought about by the intermediary of the cerebellum, and he has even localised cerebellar lesions by the absence alone of the provoked deviation of the upper and lower limbs.

The labyrinth and cerebellum are both affected.—The clinical picture is that of destruction of the labyrinth, to which is added the special motor disturbances of a cerebellar syndrome.

Treatment. Course to follow.—There is no therapeutic indication for these labyrinthine concussions. The total deafness is incurable, but it inconveniences the wounded man very little on account of its unilateral nature. The question of re-education or lip-reading does not arise.

The vertiginous disturbances disappear spontaneously in the course of time.

From the military point of view total unilateral deafness calls for transference to the auxiliary service, and partial unilateral deafness for maintenance in the combatant service, provided that the other ear is sufficiently good.

Conclusions as to the vertiginous disturbances must only be provisional, by reason of the favourable prognosis.

CHAPTER VIII

LABYRINTHINE CONCUSSION FROM EXPLOSIONS

The question of labyrinthine concussions produced by a violent noise or a sudden and considerable change of atmospheric pressure is not an entirely new one. We knew of the deafness of artillerymen and workers in caissons of which a number were observed during the building of the Paris Metropolitan Underground Railway, and which were mostly simple in nature; a short time before the war Siebenmann studied experimentally the lesions of the organ of Corti produced in guinea-pigs by intense noise.

The amount of deafness produced by the explosion of large artillery projectiles was already considerable at the end of 1914. When the special otological centres were opened at the end of the winter of 1915, they received a good number of extremely deaf men without counting those who had already been discharged.

The first idea of the majority of aurists was to attribute these deafnesses to involvement of the internal ear and consequently to look upon them as incurable. A careful examination of these patients and the course of their infirmity led to a reconsideration of this judgment, and a new tendency arose, that of

distinguishing a large number among these deafnesses as being purely functional.

Sicard published in the *Paris Medical* a series of singularly demonstrative observations of patients examined in collaboration with Bellin; Brindel announced in his reports that he had brought about many cures by purely moral means; we ourselves called attention to the persistence of the "assourdisseur" reflex and, later on, sham lip-reading. Finally, Gault, who came, somewhat later, as principal of the Centre, was struck by the number of cases of extreme deafness that he found there, whereas at the Front he only found one deaf man in 600 who had their ears examined immediately after the bombardments; he then experimented with the cochleo-palpebral reflex and came to the conclusion that a number of the cases of deafness were of "psychical" nature.

We do not profess to have written a complete history of the subject; we have not the means of doing so, and we hope that the authors whom we may have omitted to mention will pardon us.

Whatever was the cause, the evolution came into operation, more or less slowly, among first one and then another. The result was shown by a change for the better in the number of applications for discharge and even pensions:—"The number of wounded complaining of deafness is considerable. Frequent as applications for pensions were at the beginning of hostilities, so they have equally become infrequent, without, on the other hand, the number of cases examined being less." [1]

Etiology.—*Frequency.*—There are no statistics to

[1] DUCO and BLUM, *Guide du médecin dans les expertises médico-légales* (Collection Horizon), p. 111.

permit of a distinction between organic labyrinthine deafness and functional deafness. This is of no importance, for all functional deafness is, at its origin, real and organic; simulation and pithiatism appear later; simulators and hysterical men are cases of cured deafness who refuse to recognise the return of their hearing power.

The frequency of concussion-deafness is therefore great if the curable and improved cases are included among them; the severe cases are rare. We have observed 327 cases of concussion from detonation out of 6,171 patients or injured men of all sorts examined at our Centre up to October, 1916, that is, nearly as many as the cases of traumatic median otitis. In February, 1916, Lannois and Chavanne saw 1,000 cases of war-deafness, of which 262 were of pure labyrinthine concussion.

Predisposing local causes.—We are not able at the moment to establish, by personally made statistics, the influence of former lesions of the ear. It is natural to suppose that a large old tympanic perforation deprives the labyrinth of its natural protective screen. Tubo-tympanic catarrhs, counteracting good ventilation of the drum, favour the action of sudden differences of pressure on the internal ear; attention has for a long time been drawn to this point in connection with the action of pressure in the caissons and in mountain sickness. It is natural that an already defective internal ear should be more fragile.

Out of 1,000 cases of deafness Lannois counted 189 cases of otorrhœa, of which 57 per cent. were considered unfit for combatant service after a period in the trenches; and 134 cases of sclerosis, of which 48 per cent. would have to be sent to the "Auxiliary"

service, but it is not possible to make allowance for initial error of enrolment and aggravation due to faulty hygiene, humidity and want of attention.

Vicarious rôle of rupture of the tympanic membrane.—We have explained in a preceding chapter that rupture of the tympanic membrane produced by displacement of the air, saves the cochlea ; this protective action has been admitted by all authors. Its importance, however, must not be exaggerated ; we have seen more than one case of marked labyrinthine deafness occurring in spite of the rupture of the membrane.

Determining causes.—The violent displacement of the air acts on the tympanic membrane by a mechanism which we have described in connection with injuries to the middle ear. The chain of ossicles transmits the blow to the fenestra ovalis and by its intermediary to the endolymph, and from this changes take place in the internal ear on the nature of which we are unfortunately reduced to hypotheses.

Pathological anatomy.—We do not indeed know the results of an autopsy on a single deaf injured man. Prenant and Castex have, however, made some extremely interesting experiments on six rabbits and ten guinea-pigs which they rendered deaf by detonations of " 155 short," " 20 long " and a " 75." We give here their results, in their own words.[1]

" The most frequent and most characteristic histological lesions were the following :—

" (1) Dislocation of the different parts of the *ductus cochlearis*, always more marked at the first and second turns of the spiral. It is the organ of Corti itself

[1] *Paris Médical*, 10 March, 1917, analysed in the *Presse Médicale*, 6 April, 1917.

which has very often undergone great destruction (dislocated pillars, displaced external acoustic cells, Hensen's cells disturbed and even displaced). The hairs of the acoustic cells remain visible.

"(2) Several times in the scala tympani there was found considerable effusion of blood of recent occurrence, due probably to rupture of the very numerous vessels which are situated in the wall of the scala tympani.

"(3) There were noted many times on the first turn of the spiral an actual atrophy of the organ of Corti and of all the structures on the cochlear surface of the basilar membrane. The latter has the appearance of being covered with indifferent cubical cells, presenting no sensorial character. But this degeneration may also result from some injurious immobilising condition.

"(4) Examination of the spiral ganglion of Rosenthal has shown the ganglionic cells to be more shrivelled than normal.

"(5) In one case there was degeneration of the cochlear nerve in its central fibres connecting the ganglion to the brain; these fibres were demyelinised and the degeneration followed a clearly ascending course.

"(6) Integrity of the organs of the static sense noted in every case."

This integrity of the vestibule is worthy of remark; it confirms the results of clinical observation in human beings in showing that the vestibular reflexes, though often affected, are seldom abolished, and that however intense the auditory paralysis may be, the vestibular apparatus is not functionally destroyed. This immunisation of the equilibrial apparatus shows the

contrast between concussion from explosion and concussion from direct violence in which the vestibule is more often and more deeply involved. Cell and nerve lesions and hæmorrhages explain the deafness perfectly well; they correspond to severe war deafness. Slighter and more ephemeral lesions (minute hæmorrhages and intra-cellular molecular changes ?) must be kept in mind in order to explain the cases of transient deafness and the attenuated forms.

Symptoms

Ephemeral deafness.—An explosion close at hand causes a transient deafness. It is a common occurrence, and this deafness which has been attributed to a nervous exhaustion secondary to a loud sonorous sensation, hardly deserves the name of labyrinthine concussion, if it does not approach by insensible degrees to more lasting deafness.

Whatever it may be, we describe as "ephemeral deafness" the very slight degrees of concussion where symptoms only last a few hours or days and disappear without leaving any appreciable traces. It would not be correct to affirm that no real residuum remains, since a repetition of the same accident may in time produce deafness.

The deafness, or rather the slight dulness, shows itself as a disagreeable feeling of tension in the ear accompanied by buzzings or whistling; the deafness, properly so called, is not very great, and the man, if he is energetic, continues to understand conversation in spite of the subjective noises. The discomfort lasts for a few hours, after which all is again in order.

At the most the deafness remains a few days,

accompanied by violent buzzing. We have not seen it at the time, and on this subject we have only the retrospective information furnished by the injured men, but the unanimity of their statements leads us to admit their veracity, while taking into consideration the possibility of exaggeration.

A fairly large number amongst them when examined for unilateral lesions have stated that they were entirely deaf in both ears for a few hours or a few days; others presenting symptoms of a middle ear lesion only at the time of the examination complained of very great initial deafness.

There is thus reason to accept a form of labyrinthine concussion involving an ephemeral deafness, ranging from simple dulness to a very notable diminution of hearing power.

Partial deafness.—Partial deafness is very common. The patient has been totally deaf or very deaf during the first few days; he still has marked deafness at the end of some months; any possible amelioration is only to be obtained after some time; complete cure is probably impossible.

Both ears may be affected but very unequally; one of them may even have completely escaped.

This deafness presents the labyrinthine characteristics and answers to the following scheme :—

A watch on the bone is not perceived; by the air it is only heard at a few centimetres. Weber is lateralised to the good ear, Schwabach. diminished and Rinne positive.

The loud voice is only heard at 2 or 3 metres, or still less; the whispered voice is not heard at all or only on contact.

The upper limit of hearing for high-pitched tones

is more or less lowered; a considerable lowering indicates an unfavourable prognosis (Lermoyez and Lannois). The study of the cochlear reflexes [1] is of the greatest importance as much as regards prognosis as diagnosis.

An abolition or a marked diminution of the reflexes signifies a severe affection of the labyrinth and organic deafness with uncertain prognosis.

Preservation of the reflexes implies a relative functional integrity of the internal ear; should it coincide with an apparently marked deafness, the latter must be looked upon as partly or totally a functional disturbance, hysterical or simulated.

The two cochlear reflexes are, firstly, the "assourdisseur" reflex, and secondly, the cochleo-palpebral. They are considered in detail later on. The information they give is what would be expected in the partial labyrinthine deafnesses with which we are concerned at this moment.

The cochleo-palpebral reflex is diminished, that is to say, a much stronger noise than the ordinary one is necessary to provoke winking. The application of the "noise-machine" to the deafer ear does not produce raising of the voice. When applied to the good or the better ear notable voice-raising is produced, but when applied to both ears at the same time the voice-raising is more marked than when applied to the good ear alone, proving that the worse one has a certain amount of hearing-power in it.

The *disturbances of equilibrium* occupy a very secondary place as compared with the deafness.

Some injured men narrate that they were unable to reach the aid-post by themselves, that they

[1] See "Medical Reports."

staggered like drunken men and vomited for one or two days ; others recall simply a vertiginous condition and uncomfortable nausea. As a matter of fact the onset escapes our notice more often than not, for the patient loses consciousness at the time of the accident, or, if he was partly conscious, he suffers more or less from cerebral concussion and is in an emotional state.

When examined some weeks or some months after his injury, the man who has been concussed generally presents no manifest equilibrial disturbances; he walks normally without his legs being abnormally wide apart and without staggering ; he complains sometimes of sensations of dizziness, but not of acute vertiginous crises accompanied by falling down. Spontaneous nystagmus is exceptional.

It does not follow, however, that the equilibrial apparatus is always normal ; a careful examination often enough reveals anomalies of equilibrium in walking and standing upright with the eyes shut ; the patient sometimes shows a tendency to fall when standing with the feet together and the eyes shut, or still more when standing on one foot alone ; he has generally a tendency to fall either backwards or more often to the side of the deafer ear.

Still more demonstrative is the test of walking backwards and forwards with the eyes closed, as we shall describe later on according to Babinski and Weil.[1] This test, the most delicate of all, reveals the spontaneous tendency to unilateral deviation when this tendency exists in the feeblest degree ; the direction of the deviation is nearly always to the side of the affected ear. The walk, on the contrary,

[1] See page 1016

appears hesitating, without deviation either to the right or to the left, when the subject is directed backwards in the upright position.

The vestibular reactions are normal in a great number of cases, but certain anomalies will be detected if the tests are practised with care in men in whom these disturbances in walking exist. These are pre-eminently variable, and there is no apparent connection between the character of the deafness and the results of the functional examination of the labyrinth.

Barany's tests only very occasionally show caloric *inexcitability* of the labyrinth, but more often hyper-excitability, that is to say, irrigation with cold water produces nystagmus quickly, the vertiginous symptoms being very marked; still more often, however, the semi-circular canals are hypo-excitable. We have twice seen disturbances of equilibrium following irrigation with cold water operating always in the same direction as the ear irrigated; galvanic deviation took place also in the same direction as that on which the positive pole was placed.

We have never seen galvanic inexcitability, but sometimes patients have reacted to an abnormally feeble current; sometimes they could bear an abnormally strong one. Some swayed backwards, others to the side of the affected ear, whatever the direction of the current. In short, the results absolutely conform to Babinski's publications.

We repeat that these pathological symptoms revealed by systematic examination do not necessarily testify to a disorder of function of the vestibular apparatus of any practical importance; neither do they give any information as to the seriousness of

the deafness ; it is interesting to note them as objective signs of involvement of the internal ear.

Tinnitus.—Subjective noises trouble a great many patients ; they consist of buzzing and whistling ; they often last several months and the fact of their existence cannot be controlled.

Auditory hyperæsthesia.—Although deaf, the injured men dread noise ; a sudden loud sound is painful to them ; they are found to be unable to work in factories. This symptom is almost invariably present and nearly all the men wear cotton-wool in their ears. After a time they must be encouraged to overcome this exaggerated sensitiveness, but this symptom shows the danger of certain noisy modes of auditory re-education.

Headache.—A fair number of patients with labyrinthine concussion complain of headache, not very violent, but heavy and persistent. It presents the same characteristics as the headache observed by Chatelin in the subjects of injuries of the cranium, and, as a matter of fact, this author wonders if such headache may not be caused by concussion of the labyrinth. Disturbances of the venous circulation by thrombosis of the sinus, also brought forward by Chatelin, could not be considered a cause ; obliteration of the lateral sinus, which is often observed by aurists, has never produced anything of this kind.

These partial deafnesses from explosion become aggravated or ameliorated, or they remain stationary.

Fortunately aggravation is exceptionally rare. Lannois, according to Lermoyez, has noted progressive loss of the remnant of hearing in 3 out of 1,000 deafened men. One of us has published the case of

a concussed man who was suddenly seized with a severe attack of Menière's vertigo thirty-six hours after a lumbar puncture and two and a half months after the concussion. The hearing of one of the ears disappeared completely. Everything pointed to a hæmorrhage in the internal ear. Another patient, totally deaf in one ear and very dull of hearing in the other, lost the use of the latter in two or three days, whilst he complained at the same time of headache and giddiness.

Amelioration is fortunately much more frequent. Lannois and Chavanne have obtained 24 per cent. cures in a month, 22 per cent. in two months, 19 per cent. in three months, 12 per cent. in four months, the others varying between five and nine months; by cure must be understood the possibility of taking up a normal life and not complete functional restitution.

Total or almost total deafness.—The onset is identical with that of partial deafness, the hearing remaining lost in one ear or both.

Total bilateral deafness is fortunately very exceptional. Total unilateral deafness is, on the contrary, fairly frequent; we have found it in 6 out of a series of 30 cases of concussion. The deaf ear is the one which was turned towards the projectile at the time of the accident.

The ear perceives no sound; all the hearing-tests are negative; this is, however, rare; more often the shouted voice is heard on close contact and the low-toned tuning-forks during a few seconds.

No noise provokes winking when the good ear is closed. The application of the noise-machine to the affected ear produces no modification of the voice;

when applied to the good ear there is marked voice-raising; when applied simultaneously to the two ears no further increase of voice-raising is added to this.

The future course of a deafness which presents such marked signs to Lombard's test does not seem to us to promise rapid or any great improvement.

Vestibular symptoms, headache and tinnitus do not differ from those described in regard to the preceding form.

Prognosis.—It is premature as yet to predict the future in this form of deafness. A longer period is necessary before we can eliminate with more confidence the share taken by purely functional disturbances.

It is recognised, however, that these deafnesses of warfare in the severe bilateral form are exceptional, and that the others improve frequently and very decidedly.

Diagnosis

Positive diagnosis.—The positive diagnosis of a labyrinthine deafness from concussion is established from the history and the results of a complete examination bearing at the same time on the hearing and the equilibration.

If the tympanic membrane and middle ear are found to be sound, the probability is that the deafness is of labyrinthine origin, but the existence of a perforation does not eliminate *à priori* the possibility of concussion of the internal ear.

We shall not revert to the characteristics of labyrinthine deafness which is always severe and which is accompanied by an abolition or diminution of the

cochlear reflexes and involvement of the two modes of transmission of sound, *i.e.* the osseous and the aerial.

Disturbances of equilibrium are not always present, but the functional reactions of the semi-circular canals should always be carefully examined by the various tests, when anomalies will often be found. Mild disturbances of the vestibular apparatus do not absolutely prove the reality or in particular the extent of labyrinthine deafness, but they constitute presumptive evidence and show that the internal ear has been touched at least in one of its parts.

Diagnosis by lumbar puncture.—It has been said that lumbar puncture constitutes an indispensable element in the diagnosis of deafnesses from concussion. There must, however, be a clearer understanding on this matter.

The labyrinthine lesion does not of itself cause any appreciable modification in the cerebro-spinal fluid. A normal condition of the latter does not in any way signify that the labyrinth is not affected.

Lumbar puncture reveals either hypertension of the fluid or hyper-albuminosis in cases of organic concussion from explosion, but by cases of organic concussion must be understood concussion with lesions of the nervous system, not of the labyrinth. These pathological changes in the cerebro-spinal fluid indicate an injury of the cerebro-spinal axis, but by no means traumatism of the internal ear. It may be advanced that with an encephalic lesion there must be a lesion of the labyrinth as well. This presumption is not a proof and must not be accepted as such; hystero-organic associations are so frequent that the organic or functional character of each symptom

rests on the analysis of its own characteristics; the injured man may quite well have cerebro-spinal hypertension and purely hysterical motor, sensory and aural disturbances. No neurologist will deny this.

But it may again be said that hypertension and hyper-albuminosis indicate organic lesions of the central nervous system and the deafness must be attributed to this; we shall see, on the contrary, that the existence of these cerebral deafnesses is by no means demonstrated.

Finally, the protagonists of lumbar puncture ask us to accept that an injured man who has the recognised anomalies in his cerebro-spinal fluid is not entirely a simulator, that he is really ill and that the systematic practice of this exploration constitutes for the injured man a valuable guarantee from this point of view. We are absolutely agreed with regard to this principle. But why not send all these patients to the neurologist for completion of the observation instead of performing lumbar puncture ourselves? Supposing we ascertain anomalies in the fluid, we do well then to refer our patient to a neurologist; it is scarcely probable that he will be satisfied with our examination; he will perform a fresh puncture and we do not think such a repetition good either for the wounded man or for the medical report.

To resume, lumbar puncture which renders such valuable service to the aurist for the treatment of certain vertigos and for the diagnosis and treatment of meningitis, does not give any information as to the nature of a labyrinthine deafness from explosion; it only reveals the lesions of the central nervous system; it is better for the aurist to depend entirely

on his aural examination in order to appreciate the extent and the anatomical causes of the deafness, and that he should leave the lumbar puncture to his neurological confrère.

Differential diagnosis.—The distinction from deafness of median otitic origin is familiar to us; we will not go over it again.

The injured men have a habit of attributing all their aural affections to recent events. We must know how to question them. We have thus elicited several times that total unilateral deafness, falsely attributed to an explosion, in reality proceeded from old fracture of the petrous bone long before the present campaign.

We have also recognised a syphilitic origin for a labyrinthine deafness attributed by the patient quite in good faith to a concussion; certain peculiarities in the onset and course put us on our guard and a complete examination of the patient set us on the right path. Lumbar puncture has furnished us with valuable information in similar cases; it would under these circumstances be quite within our right and it would be our duty to practise it in order to effect a cytological examination of the fluid and the Wassermann reaction.

These facts show how necessary it is to examine and interrogate the wounded men with care and not to accept the truth of their assertions straight off.

Apart from organic lesions of the labyrinth, morbid changes in the auditory nerve tracts and centres may give rise to deafness with an identical acoumetric formula; such deafness always arises from a lesion of the apparatus of perception. The diagnosis is based not on the characteristics of the deafness,

but on the nerve symptoms which accompany the deafness and indicate an anatomical lesion of a particular territory. We shall devote the following chapter to this type, but we may say now that no one has ever demonstrated the existence of deafness attributable to nervous concussion from an explosion ; the aurists who have cited its existence have argued from its analogy to other paralytic or sensory disturbances noted by other authors, but they have not brought forward anatomical arguments or clinical proofs, by which we mean a statement of associated symptoms proving the existence of a focal lesion. As for the neurologists, such as Chatelin, who has seen 5,000 wounded or concussed soldiers, they only recognise organic labyrinthine deafness and functional deafness, hysterical or simulated.

There remains finally the diagnosis between labyrinthine and functional deafness. It is most important, as many mistakes have been made on this subject. We will discuss it at length in the chapters devoted to hysteria, simulation and medical reports.

It is based especially on the ascertainment of the absence or diminution of the reflexes in cases of actual lesion, and of preservation of the reflexes in the case of hysteria.

This principle of the reflexes has rendered the differentiation easy and certain. Where the diagnosis is difficult is in the mixed cases where there is voluntary or unconscious exaggeration ; hence the necessity for lengthy and minute tests which we shall describe in the chapter on Medical Reports.

Treatment.—*Early treatment.*—Cases of ear concussion, like all cases of concussion, must at first

be given rest and quiet. They experience fear of noise which makes a disagreeable impression on them ; they all wear cotton-wool in their ears and they must be allowed to do so for a time.

Rest is sufficient in the majority of cases ; it is, however, found necessary to administer sedatives such as bromide as well as antipyrin to combat the headache and obstinate insomnia.

Does the deafness call for medicinal treatment ? To prescribe iodide of potassium, as some would recommend, is to administer drugs for the pleasure of doing so. What is the use ? Paul Laurens is in favour of subcutaneous injections of pilocarpine which constitute the classical treatment of recent labyrinthine deafness in time of peace. The experience of this author is based on the results in a small number of patients ; the question is worthy of being taken up again and elucidated.

Every case of concussion is a possible " pithiatic " ; our mode of examination, our attitude towards him, our reflections, our diagnosis must be guided by the necessity of avoiding all suggestion capable of making him believe that he is deafer than he really is. It is, in effect, exceptional for the deafness not to improve spontaneously after a few days, at least in one ear.

Later treatment.—The injury is to a certain extent " consolidated " ; the spontaneous amelioration of the first few days has gone as far as can be expected of it.

The phenomena of headache, hyperacusis, giddiness have diminished or disappeared. The degree of deafness is not definitely unalterable ; we know that spontaneous improvement is still possible, but

very slowly after many months; we have now to decide as to our course of action in regard to the injured man. There are several contingencies to be considered.

Total unilateral deafness calls for an application for transfer to the auxiliary service.

Partial unilateral deafness is compatible with remaining in the combatant service and return to the regiment, provided the hearing of the other ear is sufficiently good.

Total or almost total bilateral deafness is exceptional, as we have seen; its existence is to be admitted only after detailed and repeated examination. It does exist, however, and it constitutes one of the saddest infirmities and claims our assistance. We can, alas, do nothing to improve the hearing, but we can and we ought to give the wounded man the opportunities of making up for it, to a certain extent, by lip-reading.

Lip-reading is taught in the schools for deaf-mutes; it has stood its test. The results in the case of those deafened in warfare have answered well to the expectations of those who have taken it up, and the Government has officially instituted this instruction in the majority of centres behind the Army.

It is not for us here to describe the method to be followed, but we will merely formulate a few essential principles.

The results depend greatly on the capability of the teachers; this instruction is not only a work of patience—it needs a knowledge of psychology; it does not consist entirely in teaching the deaf man to recognise a syllable on the lips but also to find out how to put together an entire phrase by means of

the various fragments that he has noted with his eyes. The deaf man, in fact, however well-trained he may be, will only read a small part of single words or fragments of words; he must be taught, from the first lessons, the work of the brain indispensable for reconstructing by means of thought what has escaped the eye.

When well instructed by specialists in the subject, the deaf men obtain immense assistance from lip-reading.

Should it be reserved entirely for the totally deaf? Should it be extended to those with great dulness of hearing?

Opinions on this point are divergent; the protagonists of auditory re-education vehemently condemn lip-reading on the ground that it allows the ears to be dulled into fatal torpor. We look upon this condemnation as purely theoretical, and we would recommend that the partially deaf should be taught lip-reading as it is likely to render them immense service, and is, after all, the systematisation of what patients have learned unconsciously to do up to the present day.

As for re-education, miracles must not be expected. It is impossible to understand how listening repeatedly to one sound can remedy a lesion. Re-education cannot make a deaf man hear, but it may succeed in teaching him to listen. Its influence is above all a moral one; it proves to him he is not so deaf as he thinks; the man injured in the war is a furious "negationist." Perhaps it will teach him better to distinguish certain consonants one from the other, and by that help him to hear the voice.

It is, therefore, only re-education by means of

the voice that we recommend, to the exclusion of apparatuses.

Too much time should not be devoted to re-education, as we cannot expect very profitable results; our injured men are impatiently awaited in the regiment, in the fields, in the factories; let us send them back as soon as we can, not, however, without having shown them, by the re-education, that we have done our best to improve their hearing; but let us be able to tell them that time is a greater teacher than we are.

Preventive treatment.—Sportsmen and artillery officers employed in shooting experiments have long known how to protect their ears against explosions, by means of "antiphones," little balls of ivory which occlude the meatus.

Could the number of concussions not be diminished by the use of a "war antiphone"? The problem is a complex one, for the combatant must not be made deaf under the pretext of protecting the ears.

Niel has drawn attention to this question; Wicart has suggested filling the auditory meatuses with cotton-wool moistened with glycerine and covering the ears and the mastoid regions with ear-caps stuffed with carded cotton; Bardier has brought out a protector constructed on this principle, and has shown that it does not deafen the soldier to an inconvenient extent. It remains to demonstrate the efficacy of these means and the possibility of putting them into practice. To fill up the ears of a battalion, in a trench, with cotton-wool moistened with carbolised glycerine, at the time of a bombardment, does not appear *à priori* a convenient proceeding.

Laimé's apparatus is simpler, and the man can put

it on or take it off instantaneously. It is composed of two metal drums which cover the ears and are fitted

FIG. 10.—Laimé's protector.

to the integuments by a pad of indiarubber inflated with air. We do not possess any information as to its efficacy.

CHAPTER IX

DEAFNESS FROM LESIONS OF THE AUDITORY NERVE TRACTS

The labyrinthine deafnesses considered in the preceding chapter represent the peripheral group of lesions of the percipient apparatus; they are by far the most numerous and are to be explained by deteriorations in the auditory nerve-endings. This sensory paralysis affects the two branches—the cochlear and vestibular—when deafness and abolition of Barany's reflexes are observed at the same time. We have seen this syndrome occurring frequently after fractures of the petrous bone and damage produced by the blow of a projectile on the cranium. Labyrinthine concussion from shell-" wind " generally causes deafness without paralysis of the vestibular nerve. The lesions which we are now about to consider and which touch the course of the auditory nerve tracts, derive their characteristic symptoms from changes in other nerve tracts involved at the same time.

Some of these auditory tracts are not particularly well sheltered from traumatism; wounds in these regions, however, occur so rarely that we do not know of one example published during the war; we shall, therefore, devote only a few lines to this chapter,

contenting ourselves with recalling briefly the symptoms attributable to the different lesions, non-traumatic in themselves, of the auditory tracts. This will save us from discussing their differential diagnosis when we are considering the other varieties of deafness in order to define in particular the difference between purely functional disturbances and those due to organic lesions of the nervous system.

Lesions of the trunk.—The nerve, which belongs to the eighth pair, is exposed, in the internal auditory meatus and the posterior cranial fossa, to compression from fracture, exostoses, gummata, patches of meningitis or abscesses. The facial nerve accompanies it, so that deafness and paralysis of the vestibular and facial nerves may be seen together. A similar association is met with in certain otorrhœas complicated by labyrinthitis, but in this case the aural lesions will be evident and will admit of no doubt.

Compression from a tumour in the ponto-cerebellar angle gives rise to a symptomatology which has been carefully studied by Lannois and Chavanne : namely, trigeminal neuralgia and ocular paralysis occurring in addition to the deafness, facial paralysis and vertigo.

Cerebral tumours produce bilateral hypoacusis by compression of the trunk of the eighth nerve and by cerebro-spinal hypertension.

Tumours of the cerebellum produce bilateral or unilateral deafness generally associated with facial paralysis.

Bulb and isthmus of the encephalon.—The decussation of the auditory nerve fibres is incomplete ; therefore, unilateral deafness is partial when it is

owing to a lesion of the bulb or isthmus of the encephalon. The auditory fibres are separate from the vestibular ones and the deafness is unaccompanied by vertigo. Bulbar foci of softening secondary to arterial lesions can give rise to varying symptoms among which vertiginous disturbances sometimes predominate, but the deafness is incomplete and ordinarily transient.

Tumours of the bulb cause hypoacusis on the side of the lesion in a quarter of the cases. Tumours of the pons cause deafness, which is sometimes crossed ; those of the corpora quadrigemina bilateral deafness if they themselves are bilateral, or unilateral and crossed if the contrary is the case.

Cerebral deafness.—We have lately described as cerebral a whole variety of types of deafness which appear very different the one from the other. Some of them are thus designated because they do not appear to depend on an aural lesion, others because they form part of a syndrome in which so-called cerebral phenomena, such as amnesia, hebetude, mental confusion, predominate ; others, again, because there is good reason to connect them with cortical lesions.

These cerebral deafnesses are also called psychic, emotional, " concussion " or hysterical, etc.

Such confusion is not worthy of modern otology. We must reserve the title of " cerebral " absolutely for deafness caused by changes in the auditory cortical centre.

We must absolutely define the deafness by an analysis of its exact clinical characteristics rather than by estimating the emotional disturbances which are associated with it ; otherwise we shall be rendering no service to the neurologist.

A sufferer from concussion may not present any psychical disturbance but may nevertheless be the subject of hysterical deafness ; another may be affected with real and indisputable lesion of the internal ear and may in addition complain of severe emotional phenomena.

In the light of this, do traumatisms frequently produce cerebral lesions causing deafness ? We do not think so.

A jolt or violent shock induces what is known as cerebral concussion, that is to say a kind of shaking-up of the nerve cells and perhaps minute hæmorrhages, causing motor and sensory disturbances which may vary from mental clouding to unconsciousness and absolute immobility. All the senses are affected including that of hearing. But these sensory disturbances of concussive origin soon pass off unless there is added to them an element of pithiatism.

Beyond this " dizziness " which follows the shock does there exist a permanent deafness produced by lasting lesions of the auditory nerve-centres ?

This centre occupies the middle part of the first temporal convolution.[1] Neither of them, the right nor the left, corresponds entirely to the opposite ear on account of the incompleteness of the decussation of the nerve bundles at the level of the bulb. Symmetrical and bilateral foci of softening produce marked disturbances of hearing and even complete deafness. These are exceptional events.

Otitic abscesses of the temporal lobe fairly often produce aphasia, very exceptionally deafness, and meanwhile the affected ear being deaf, the hearing of

[1] This view is not accepted by all. (See Chatelin and De Martel *Horizon Collection.*)

the healthy one should be compromised by the temporal lesion of the opposite side and the disturbances of audition should be well marked. This proves what a slight tendency there is for cortical lesions to produce deafness.

Deafness from direct traumatic lesion of the cranium is possible; as we have just seen, it could only amount to hypoacusis on account of the incomplete decussation; it is certainly very rare. We do not know a single example.

It seems still more difficult to admit, otherwise than as a very exceptional event, the occurrence of deafness from cerebral lesions resulting from explosion; first of all because such foci are rare; paralyses due to a similar cause are exceptional (Claude); very few cases of aphasia have been observed and the majority of them are probably of a hysterical or toxic nature (Dumas), for they are often to be observed after simple emotion without any concussion. The mutism so frequently observed is of a hysterical nature. The deafness termed "cerebral" is hysterical or labyrinthine, and if auditory disturbances really due to a lesion of the centres ever show themselves, they will constitute an exceedingly rare exception and cannot take the form of total deafness unless the lesions are bilateral.

CHAPTER X

FUNCTIONAL DEAFNESS
HYSTERO-PITHIATISM—SIMULATION

A functional disturbance is to be distinguished from an organic disturbance in that it does not answer to a recognised anatomical lesion; the proof is that it is susceptible of disappearing completely and suddenly under a purely moral influence.

Do there exist deafnesses answering to this description? The response is unquestionable. Lannois and Chavanne have cured 15 deaf men out of 32 in one sitting.

HYSTERO-PITHIATISM

Definition.—It is impossible to describe aural hysteria without being constantly inspired by Babinski's conclusions which neurologists have almost unanimously accepted, and which Babinski and Froment have clearly set forth in their recent work.[1]

Babinski has not done away with hysteria; he has defined its limits; it has become "pithiatism,"[2]

[1] Babinski and Froment, *Hystéro-pithiatisme et troubles réflexes* (Military Medical Manuals, University of London Press).

[2] *πείθω*, I persuade; *-ιάτος*, curable.

that is to say, the predisposition to exhibit certain morbid phenomena which can be created entirely by suggestion and completely cured by the same mechanism. Hysteria reproduces all that suggestion may create, movement or immobility, imaginary sensation or sensitive and sensory anæsthesia, but beyond that it has no power; it may cause the most severe and lasting paralysis, but it cannot bring about the most transient reddening or pallor. There is one essential point; it has no influence on the reflexes.

The hysterical state is distinct from the emotional state, for the latter is accompanied by constitutional phenomena, cardio-vascular, secretory disturbances, etc., which suggestion cannot reproduce or cure. Emotion does not directly create a hysterical phenomenon, but it places the subject in a state of suggestibility which is pre-eminently favourable.

The pithiatic differs, on the other hand, from the simulator in that he has not willed his illness; it has been imposed on him by an outside influence or an auto-suggestion of which he is unconscious; hysteria is an unconscious simulation. The simulator, on the contrary, has entirely conjured up his illness. He does not wish to get well. We should be wrong in saying that the hysterical subject wishes to be cured; he may like his disease either because it enables him to play a part or because he finds advantage in it; from this point of view hysteria is a semi-simulation. Thus pithiatism exists distinct from simulation, but in a hysterical subject the two elements are sometimes united in a proportion which is difficult to determine.

Etiology.—Never have men had their nervous systems submitted to such severe trials as our infantry

of to-day ; physical fatigue, moral anguish, terrifying sights surpass anything that has hitherto been known ; the deafness alone arising from an intense and prolonged bombardment produces a nervous depression from which there is no escape. What better soil for the development of hysteria ? The faculties of reason and of will disappear and the individual finds himself at the mercy of any suggestion that comes near him.

Babinski attaches little importance to the personal or hereditary antecedents in connection with the genesis of those casualties which we are considering and which arise from " minor hysteria " ; " if the major hysteria," he says, " scarcely develops except in subjects predisposed by their birth and their nervous antecedents, if it is the lot of the neuropathic aristocracy, the ' minor hysteria,' on the contrary, is within the reach of everybody." It has seemed to us, however, that the personal equation enters into the calculation ; the worst and most inveterate forms of pithiatic deafness occur mostly in illiterate or very ignorant peasants ; these unfortunate men harden themselves, more than any others, against the attempts of medical suggestion. Appearing to understand nothing, they submit to methods of examination with a bad grace and in fear ; apparently almost indifferent to their lot, they show no desire to become cured ; they have no moral force, nothing in them which could be taken hold of in order to get a grip on them with methodical persuasion.

Pithiatic deafness shows itself especially after the explosion of very large projectiles and particularly of mines ; the emotional state produced by the death of comrades, by being himself buried, leaves the man

defenceless against auto-suggestion ; the emotion by itself would have no power ; there must be suggestion to cause the deafness.

It is not by chance that the wounded man suggests to himself that he is deaf ; there is even no need for such auto-suggestion, for he is really very deaf or at least very much deafened. The aural concussion produced by these noises and the displacements of air of unprecedented violence, do not always leave behind them a permanent labyrinthine lesion, but a kind of auditory stupor accompanied by noises ; " one must make an effort to listen," a confrère who had often passed through these terrible experiences said to me ; those who do not force themselves to listen are deaf. Many of our wounded, who are not subjects of pithiatism, affected with a unilateral traumatic lesion of the middle ear, have assured us that they heard nothing for twenty-four or forty-eight hours. Once this period of stupor is passed, normal subjects begin to hear again, but not so the pithiatics.

Depressed to the utmost limit of lassitude and asthenia, they accept their deafness as a natural consequence of events and do not try in any way to overcome it. On the contrary, they do not think of it except to become more deeply weighed down by the idea that they have lost their hearing.[1]

Auto-suggestion has been enough to create the symptom, but hetero-suggestion will exert itself powerfully to augment the effects and to render them more permanent. Directed to a hospital centre, our unfortunate man comes in contact with many other deaf men ; he will see more than one whom the doctors

[1] DUMAS, *Soc. de Neurologie*, 1916.

are unable to cure. Perhaps some nurse (this is becoming rarer to-day) may pronounce some clumsy words of pity with regard to his misfortune; medical examinations, trials of local treatment, if they are prolonged and fruitless, will convince him still more of the reality of his deafness. All this is classic and hackneyed, and there would be no need to insist on it if it were not necessary for us to remember how careful doctors must be in entering their diagnoses on the various hospital slips and bulletins. Why do we not content ourselves with writing—"apparent deafness," "deafness, detained for observation," "concussion," until we are able to establish an exact diagnosis? We have too often seen "dislocation of the chain of auditory ossicles," "hæmorrhagic internal otitis," "destruction of auditory organs," "incurable deafness." Let us beware also of discussing the matter before the patient. A young junior officer, apparently sincere and intelligent, said to us one day, "I cannot hear; I have no light spot."

Clinical description.—We shall describe three forms of aural hysteria—deaf-mutism, total deafness, and extreme dulness of hearing.

Deaf-mutism.—Deaf-mutism represents the most accentuated form of traumatic hysteria of the ear.

We know *à priori*, for certain, that mutism which supervenes under such circumstances, is a purely pithiatic symptom; but it is not the same with regard to the deafness which is not necessarily pithiatic; it is possible to imagine the combination of an organic deafness and a hysterical mutism.

It is difficult to recognise the real nature of the deafness on account of the conditions of examination; all the hearing tests are negative; the patient hears

no sound; this, it is true, is very suspicious, for total destruction of the two labyrinths is exceedingly exceptional; there can be no question of noting the voice while using the noise-machines; there is, however, one reflex which remains to us, namely, the cochleo-palpebral; it is of great value. Supposing a slight noise emitted unexpectedly causes the patient to wink, we have the indisputable right to affirm that he has no severe organic lesion of the auditory apparatus. Absence of the reflex, on the contrary, obliges us to be reserved in our opinion.

The mutism is absolute; the patient utters no sound by the mouth; he does not speak, he does not whistle; he makes no attempt to articulate a word or syllable; he has, however, retained the memory of language; he reads and writes. The man with aphasia, on the contrary, articulates certain words, but in their wrong connection; his glottis works, but he has lost his memory for words.

The laryngoscope reveals a perpetually gaping glottis; the cords make no movement when the patient is asked to utter the sound "eh" and no laryngeal sound is emitted. This pseudo-paralysis is not met with in any known organic lesion; we possess, however, another powerful argument for calling this hysterical condition a sham one, for Janet, quoted by Dumas,[1] has erroneously written, "We know of no way of causing the cords to come together except asking the patient to call out or utter a sound, but we are concerned with people who can neither call out nor speak and who consequently cannot produce the movements which we ask for"; the immobility of the vocal cords is of pithiatic origin; it

[1] *Revue de Paris*, 1er trimestre, 1917.

is limited to movements which the will can command or stop, but the *motor reflex is preserved*; if we make our patient inhale sulphurous acid he will give a sonorous cough; if we provoke the nausea reflex by working the laryngeal mirror about, we shall see the arytenoids come together, so that the constrictors of the glottis perform their function, their paralysis being only apparent.

Besides, organic laryngeal paralysis produces aphonia and not mutism; not only do the vocal cords of the mute remain immobile, but the tongue, the lips and soft palate remain inert during speech, whilst deglutition takes place normally. The purely pithiatic nature of the mutism is, therefore, incontestable.

Roussy has distinguished three varieties of deaf-mutism:—the first consists only of the pithiatic occurrence of deafness and mutism; apart from this the patient is normal, he speaks by gestures and by writing; in the other two, mental confusion is superadded; the patient is either agitated, frightened, haggard with the mental confusion of delirium, or he is stupid and indifferent to everything, with the mental confusion of stupidity.

Course.—The prognosis of deaf-mutism is favourable. Cure always takes place more or less rapidly according to the surroundings and according to the quality of the persuasive treatment. Speech does not at once recover its normal tone; it often remains hesitating and jerky for a time. The return of the hearing depends on the absolute or comparative soundness of the ears.

The presence of delirious or torpid mental confusion makes the situation much more gloomy. Therapeutic

suggestion becomes impossible; besides, the patient no longer belongs to us; the aurist must hasten to resign his place to the psychiatrist as soon as he has completed his otological investigations.

Total or almost total deafness.—Pithiatic deafness is generally bilateral, or, more frequently still, an organic unilateral deafness is complicated by a hysterical deafness of the other side.

The hearing-tests reveal extreme or total deafness for all sounds, as well by bone-conduction as by air-conduction; however—and this is an essential point—the reflexes are preserved. The deaf man who hardly hears you shout, hears himself speak, and regulates his own voice according to his hearing; he shouts when the assourdisseur is used (Lombard); he winks at an unexpected sound in the neighbourhood of his ear (Gault); this preservation of the aural reflexes is as significant as the pupillary contraction in hysterical amaurosis; it altogether eliminates the hypothesis of severe organic deafness.

This does not mean that the hearing is really normal and that the ears are absolutely sound; it merely shows that the hearing is not very much diminished and that the lesions are not severe. It must be remembered that pithiatism may aggravate a real lesion, and it is this association which sometimes renders the problems submitted to the expert so difficult.

Certain hearing-tests are added to the consideration of the reflexes in order to differentiate between organic and functional deafness. These are described in detail in the chapter on Medical Reports, to which we would refer the reader, who will also find the means of distinguishing between hysterical and simulated

deafness in the portion of this chapter which we shall devote to simulation.

Dulness of hearing.—Partial hysterical deafness is distinguished from organic deafness by the preservation of the reflexes and the apparently paradoxical result of certain hearing-tests (Weber's, Stenger's tests, etc.). It is not easy to differentiate it from simulation, and we believe that simulation plays the principal rôle in it; much as we believe in the possibility of total or almost total functional but involuntary deafness, we have equally little belief in simple dulness of hearing. We shall discuss this difficult point of diagnosis later on.

All authors are agreed in describing the difference in the general attitude and outward appearance between the organically and functionally deaf. The really deaf man is extremely melancholy; he cannot be consoled for being isolated from the rest of mankind; he looks upon his life as ruined; he worries about his chance of becoming cured; he follows with his eyes the people who are around him; he never ceases to be interested in what is to be seen around him.

The hysterical man shows, on the contrary, an extraordinary indifference both as to his own lot and to all that is passing around him. He is an automaton to an extreme degree, immobile, set, looking into space; he does not appear to suffer through his infirmity, and soon lives the life of the other injured men in the hospital, that is to say, as long as he has no superadded mental disturbances.

Prognosis.—The course of hystero-traumatic deafness does not follow any fixed rule. It varies to an

infinite degree with the mentality of the patient, his good will, his intellectual and moral value, the intensity of the emotional phenomena, the atmosphere by which he is surrounded, and the manner in which he is treated. An intelligent young man who has good will and self-respect and a desire to be cured, will rapidly improve if he falls into the hands of an aurist who does not find an imaginary lesion, inflict unsuitable local treatment on him or practise suggestion in the wrong direction. The injured man who is somewhat illiterate, glad to have left his regiment and desirous not to return to it but to go home as a pensioner of the State, who knows that deafness is often incurable because he has seen it treated without good results, and who has a right to imagine himself ill as he is cared for with great show by means as odd as they are classical, such a man does not become cured; even when he is placed in good conditions he will still remain uncured, because everything has actually been put in working order for "driving in the nail."

Treatment.—The conclusion to be arrived at from the preceding lines is that there is a series of conditions to be considered if we would prevent severe forms of traumatic hysteria. From the time of the accident the different medical authorities before whom the concussed man comes must avoid mentioning a decided diagnosis of an aural lesion before a systematic examination has been practised.

This examination requires an installation with the necessary instruments, which, however, is quite trifling, as will be seen in the chapter devoted to Medical Reports; and the doctor must in particular

be competent to carry out this type of investigation. Babinski, Vincent and others have repeatedly insisted that a sure and exact diagnosis must precede all attempt at psycho-therapy, for to treat organic lesions by suggestion is to experience failures which lower the prestige of the treatment. The recognised pithiatic man should be separated from the organically deaf, whose example would be far from being salutary, and, further, he should be completely isolated.

The care with which the aurist proceeds with his examination and his air of authority give confidence to the unfortunate man ; the best plan is not to deny the existence of an aural affection at first, but to assert quite naturally that he is free from serious lesion and likely to get well quickly with quiet and rest. During the next few days, according to Gault, "winking" may be advanced as a proof that the hearing has returned, but perhaps it is most advisable, when face to face with the patient, to proceed for the most part with assurances rather than arguments. The sojourn in the otological clinic should not in any way be prolonged ; if the patient recovers his hearing he should be sent away for a short period of convalescence with the indispensable precaution that a very exact and precise statement of the condition of his hearing at the time of his discharge from hospital should be written on his hospital report, failing which a relapse would be very likely to occur when he is in his own home. Should the aurist come to a deadlock he would only lose his time and his prestige by delay, and would do better to send the patient to a modern neurological clinic where appropriate psycho-therapy would be employed by practised experts.

Success is generally obtainable when the accident has taken place only a few days or weeks previously. It becomes very problematical when the case is that of a man injured long before, and who has been the object of diverse diagnoses and attentions, who has known many cases of uncured deafness, and above all who has perceived in his deafness a definite means for not returning to the fighting. He becomes a pithiatic and a simulator, the simulation being superadded in an indefinable proportion ; but inasmuch as they are pithiatics, they are patients who must only be returned to the Army when they are cured ; their commanders can make no use of them, and their remaining inactive in the depôts is a nuisance from every point of view.

Babinski recommends trying abrupt treatment straight away ; this method affords him many successes in curing motor disturbances ; we have seen that Lannois and Chavanne have had recourse to it ; it consists in taking advantage of the emotion produced by arrival at a new hospital, of the moral ascendancy of a fresh expert who gains the patient's confidence at the onset, and assures him authoritatively that his ear is not destroyed, that he can hear, that he must hear, that he does hear. " If such declarations appear to humiliate him he should be made to feel that such a state of mind, after the concussion to which he has been submitted, is compatible with very sound intelligence, excellent morale and great courage." [1] This persuasive assault seldom succeeds except with subjects of a certain amount of culture and moral tone.

How are we to act if the first attempt fails ?

[1] BABINSKI and FROMENT, *loc. cit.*

Some have advised instituting an appearance of treatment for these imaginary deafnesses with the idea of suggesting progressive amelioration in the first place and finally cure; they are submitted to our old therapeutic proceedings—massage of the tympanic membrane, insufflations, catheterisations. But to irritate an ear which is not to be benefited by such treatment, is to deafen it momentarily, a condition little favourable to the desired suggestion, and to persist in such manipulation is to risk driving in the malady rather than to eradicate it.

We must, however, do something; discreet re-education is then permissible. But the significance of such re-education must be understood; it is only an appearance; it has not for its object the teaching of hearing over again to one who has not lost the power; its only object is suggestion. It should be of the very simplest; the teacher should show his pupil, if he wishes to obtain his confidence and attention, that he will hear simple noises and sounds first and more complicated ones later. This re-education, in some ways purely moral, should also be as little systematic as possible; it will serve to elicit the good will and intelligence of the patient; it should not be continued in case of failure. *The teacher must be warned that he is between two great risks—that of believing that it is he who cures the deafness and that of exercising a contrary suggestion.*

On no account should these patients be kept long in otological clinics; they should be sent to a neurological clinic when they do not improve rapidly. They should take with them a case-paper containing details on which the aurist has noted his diagnosis of functional or hystero-organic deafness, and on

which he has clearly and fully set forth his opinion. Our modern neurologists are often marvellously experienced and equipped for the cure of these pithiatic disturbances which belong more to them than to us, while they alone are at the same time qualified to appreciate the nervous or mental disturbances associated with the deafness.

However, they sometimes fail. In the same way that a trouble will not be cured until the removal of its cause, so many pithiatic disturbances will not disappear until after the War.

Of course if we find ourselves confronted by a hystero-organic combination and if the organic lesion allows of a course of treatment favourable to the patient, advantage must be taken of it, this being the most efficacious treatment. For example, if there should be a unilateral organic deafness with pithiatic deafness of the other ear—a frequent combination—we must not hesitate to propose our man for the auxiliary service; we shall then not have much difficulty in persuading him that he hears with the good ear.

SIMULATION

Simulation of total deafness is rare; exaggeration of real dulness of hearing is more frequent; the attempt at fraud pertains only to the severity of the infirmity or to its severity and its origin, according as the patient is content to exaggerate a war-deafness or wishes to attribute a recent traumatic origin to a lesion which is certainly of old standing.

Etiology.—We did not see one simulator during our sojourn in a divisional ambulance; simulation

is not a malady of the Front; it is contracted behind the lines and above all at home; it is contagious and is caught either in the hospital or during convalescence; little epidemics are to be observed when the nosocomial surroundings favour its development.

We hardly know of any individual predisposition for exaggeration; it is so conformable to our poor human nature! On the other hand, simulation of total deafness is especially observed among soldiers without intellectual culture; it constitutes a veritable torture for a man with even a small amount of intelligence, unless he sets up for being a lip-reader.

Symptoms and diagnosis.—A. **Total deafness.**—Simulated deafness is the most absolute; no sound at all is perceived and all the hearing tests are negative.

The "assourdisseur" and cochleo-palpebral reflexes are present in their normal form, and there would be nothing to differentiate the simulator from the hysterical subject unless he professed often to be able to lip-read when he really does not read, but hears like any one else. We shall explain at length in the chapter on Medical Reports our way of finding out sham lip-reading. We would only say here that we consider it a proof of conscious falsehood, while Babinski and Froment look upon it as a manifestation of hysteria; it does not seem possible to us that the simulator of deafness should unconsciously play this farce of learning lip-reading by degrees and that he should ignore hearing us when he has his ears as the only means of understanding us. The attitude of the simulator who does not lip-read has attracted the attention of all observers, as it is so singular; the

man, feeling himself observed, tries his utmost not to become agitated; he knows himself to be at the mercy of a surprise or a start; he is also nervous and generally keeps his eyes fixed on the ground, always keeping apart from people or things going on around him; it is not the automatism, the natural indifference of the pithiatic; it is voluntary abstention from all movement and all imitation.

Unfortunately an attitude does not constitute a sufficient basis for the formation of a medical report. If the preservation of the reflexes differentiates in a certain and objective way between organic and functional deafness, the distinction between hysteria and simulation is often impossible; we shall see presently that this is not of practical importance.

B. **Partial deafness.**—The man acknowledges that he hears something; the different hearing tests allow of our judging between what is true and what is false in the way we shall show in the following chapter. Although relatively easy to distinguish it from true organic deafness, it is still difficult to make the diagnosis between it and hysteria.

Conscious and unconscious simulators have in common the preservation of the reflexes and an erroneous appearance of deafness when the affected ear is apparently being tested, but at the same time the hearing of the good ear is being observed (perception of sharp sounds with the deaf ear, the absence of the "false" negative Rinne, paradoxical Weber while the good ear is stopped up, Stenger's, Escat's and Bourgeois' experiments). But the characteristic of the simulator is the great variability of his answers; he is generally caught by the test of the loud voice, with the eyes shut.

We have described the classical attitude of a man falsely affecting total deafness; that of the partially deaf deserves also a few lines. Far from being motionless, he makes signs in an exaggerated manner; he will not hear except at close quarters and then very badly; if you question him he gets up after you have spoken, leans towards you almost touching your face; he repeats your question in order to impress the fact on you that he has not heard it; it is not enough to say he repeats it; he shouts it out. This bit of business is not constant, but fairly frequent and characteristic.

Course to be followed.—It is a serious matter to certify on a medical observation sheet that a man is a simulator, and this should not be done without absolute certainty. The aurist should remember the possibility of hystero-organic association and the difficulty of diagnosing between hysteria and simulation; he will remember also that the simulator is often suffering mentally and really ill. Our rôle is not to accuse but to cure; hysterical subjects and simulators can be cured by moral influence, and we should in the first place have recourse to it; we may be pardoned for failing where suggestion is concerned because it is not our profession, but belongs to others who have been trained in practising it.

Let us confine ourselves to a detailed examination of these patients; let us establish a precise diagnosis of functional deafness, and let us refer them to our neighbour, the neurologist, with a very complete report.

As for exaggerators, let us treat them according to their genuine infirmity. It is not enough to say that a man exaggerates; we must in any case

know what he is worth from the auditory point of view and classify him according to this valuation; we are not appointed to fill the depôts with semi-deaf men or even exaggerators, but to put each in his place.

FOURTH PART

MEDICAL REPORTS

The drawing-up of medical reports may not in this war constitute the aurist's most important work, for, to-day as always, medicine is before everything else the art of healing; but it has revealed to us some of the most difficult and newest problems.

The number of affected ears exceeds all anticipation; total or partial deafnesses, permanent or curable, real or simulated, require frequent examination in regard to the question of discharge or indemnification.

Otorrhœics and partially deaf men have been incorporated in large numbers and the greater part of these are perfectly fit for combatant service; they will prove to be useful soldiers provided those in command are assured that they can and ought to serve. If wrongly selected they become a dead weight in the Army, an encumbrance to the hospitals and a social evil.

Medical reports have, then, as their aim, the indemnification of those with severe traumatic deafness, and the discrimination between those who are fit, those suitable for auxiliary service and those for exemption. They resemble in many points the medical reports of peace time, on accidents during

work or in the street, but the war has considerably enlarged the field of our observations and calls for the application of important new methods.

The expert must not look upon himself as the advocate either of the State or of the injured man. He takes neither side ; he surrounds himself with all the data which go to confirm the statements of the man while he takes all necessary precautions for testing his sincerity and guarding against any possible exaggeration. He does not, *à priori*, look upon all the patients as simulators ; he commences his examination without any pre-conceived idea.

The medical report will include the previous history, objective examination and functional tests of hearing and equilibrium.

CHAPTER XI

PREVIOUS HISTORIES

A consideration of the previous histories is of great importance.

We find out whether the patient had discharge and suppuration from the ear before the war, ascertain precisely the duration of such and the mode of treatment adopted. We enquire also as to the hearing. The fact of his having followed a particular profession proves that the injured man could not have been very deaf; we must know whether he has been declared "fit" for military service, or if he has been exempted, and why? Extreme deafness being incompatible with active service, we would admit that it could not have existed at the beginning of the war.

A man with dulness of hearing and presenting ordinary lesions of the tympanum such as retraction of the membrane, is to be suspected at once if he attributes his infirmity to a recent injury; it is, therefore, a good plan to order an enquiry to be made by the constabulary of the neighbourhood he previously frequented; we can also write to the officer in command of his company to find out if he was known to be deaf before his injury.

We acknowledge that these official researches rarely have satisfactory results: the regimental

enquiry because it is difficult to remember these points, often on account of the witnesses having disappeared; that of the constable because the veracity of neighbours and comrades is open to question. Nevertheless, this element of information should not be neglected.

The official request for an enquiry might be worded as follows :—

"*The principal Medical Officer of the Centre O.R.L. To the Officer commanding the Constabulary of N . . .*

"I beg to request you to be good enough to proceed with a discreet enquiry with regard to the deafness of the man named X . . . formerly in the Army.

"We wish to know what profession he followed and whether he was looked upon as deaf or dull of hearing.

"It will be necessary to enquire of his neighbours, his workshop companions, etc., in the first place, and as a last resort, his relations and parents."

The circumstances connected with the injury are carefully set down; the position of the man in relation to the exploded projectile has, we believe, a certain value, the deafness being generally much more pronounced in the ear turned towards the projectile; being buried produces an intensely emotional state favourable to the development of functional deafness; the unhappy men who have seen the same shell kill their comrades around them are equally predisposed to this condition.

We enquire, in regard to the immediate consequences, as to loss of consciousness, loss of

memory, total deafness, bleeding from the ear. The word "vertigo" should never be mentioned, but we ask the injured man how he got up, how he arrived at the aid-post, if he was able to walk alone directly afterwards and during the following few days, if he had nausea and vomiting; we enquire as to when the discharge from the ear commenced, as to its nature, its quantity and the treatment employed.

The discharge papers and the various hospital reports will be collated in order to find out any mention of deafness, tympanic rupture or otitis, and accurate information with regard to the onset and course will be insisted on.

Not one of these details is superfluous; this enquiry, if well conducted, furnishes important points in establishing the sincerity of the man interested, as it may also prove his bad faith in a very evident manner.

Let us take a few examples from among the most frequent: a man is injured in the limbs; he is discharged on an ambulance with a paper mentioning this injury exclusively; he passes through several hospitals without one report mentioning a lesion of the ear; he decides eventually to complain of deafness which he attributes to an explosion; you examine him; you ascertain old lesions and you can affirm almost positively that his history is false from beginning to end. A second example: an injured man is discharged and treated for a left-sided traumatic deafness; he obtains leave for convalescence; he returns to his regiment completely deaf in both ears and unfit for service. Is not this history very suspicious from the beginning?

The expert should, therefore, proceed with this

enquiry with the vigorous method of an examining magistrate, without omitting anything and always exacting precise answers checked by the papers he holds in his hands, allowance being made, moreover, for possible imperfections in these papers.

CHAPTER XII

OBJECTIVE EXAMINATION

Traumatic deafnesses follow either blows on some part of the cranium which transmits them to the internal ear, or injuries of the organ of hearing itself.

In the first case the expert describes the character of the cicatrices, carefully noting their situation and the condition of the subjacent bone ; the description need not be a long one.

The anatomical condition of the ear necessitates on the contrary a detailed statement mentioning exactly the normal or abnormal condition of each part.

We pass quickly over cicatricial lesions of the auricle and auditory meatus, because their traumatic origin is as a rule free from doubt.

The presence of blood or of a clot at the bottom of the meatus is a point of considerable importance when the injured man is seen soon after the accident, for it furnishes a practically indisputable proof of recent traumatism.

One of the principal difficulties in making a medical report rests, on the contrary, in distinguishing old lesions from recent injuries of the tympanic membrane and cavity.

The membrane is generally normal in cases of

extreme deafness following concussion. It has fairly often seemed to us to be depressed under similar circumstances, and we ask ourselves if there exists here a simple coincidence between an old-standing condition and a recent explosion, or whether a sudden and violent displacement of air cannot produce a definite change in the position of the membrane and ossicles; this would be a possible mechanism for the genesis of certain deafnesses. Experiments on animals would probably give us information on this point.

We must distinguish between this simple driving in, which is perhaps traumatic, and depressions and pathological retractions following an *old tubo-tympanic catarrh*. The handle of the malleus is then retracted and more or less horizontal, the promontory and the anterior and posterior folds project; the appearance of the membrane is altered; concomitant naso-pharyngeal lesions are found. The membrane without being retracted may look dull, lustreless and dark, it may present calcareous infiltrations or zones of thickening or atrophy; these lesions, indicative of old-standing sclerosis of the tympanum, are easy to differentiate, but we cannot always distinguish between a cicatrix of a few months' duration, due to the war, and an older pathological condition. Recent injuries of the tympanic membrane are recognisable, as we have seen, by the presence of blood and later of a clot in the depth of the meatus.

Sometimes an ecchymosis is all that may be seen on the membrane; this is a very important point. Again, a recent non-infected perforation may be recognised by the surrounding parts being normal. If infected and complicated by a profuse suppuration

which pulsates, it is difficult to distinguish it from an ordinary acute otitis. When seen after several months it cannot in any way be differentiated from a chronic suppurative or cicatricial otitis. There are, however, numerous cases in which the old-standing pathological nature of the otitis is indisputable. We do not acknowledge, for example, the possibility of traumatic perforations of Shrapnell's membrane. Certain well-marked lesions of the tympanum with very pronounced retraction or partial destruction of the malleus, an old-standing cicatricial appearance of the zone of the promontory, etc., do not present any doubt to an experienced eye.

Our objective examination here reaches its limit. Less fortunate than the oculist who can see the retina, we cannot directly ascertain lesions of the internal ear, and we have to resign ourselves to our inability to identify them except by the functional disturbances.

CHAPTER XIII

FUNCTIONAL EXAMINATION OF AUDITION

It is not enough in these days to draw conclusions from impressions, to argue from the patient's attitude assumed to be more or less sincere, to prepare traps for him, to be a rival with him in ruse and patience. We must investigate his hearing-power methodically, making it, as far as we can, impossible for him to deceive us, and above all we must control his statements by a study of the reflexes which are independent of the will.

The discovery of the cochlear reflexes raises the medical reporting in regard to the ears to a degree of precision hitherto impracticable, and greatly increases the value of the conclusions.

There is an enormous difference between a medical "report" and a clinical observation; whoever prepares the first in the same way as he would make the latter lays himself open to gross errors.

Clinical observation requires the absolute good faith of the observer and the subject. If there is a chance of the reader suspecting either one or the other, the observation counts for nothing; the sincerity of both parties must be admitted *a priori*.

In the making of a medical report the moral and

scientific status of the doctor is above suspicion. The State is possessed of every possible guarantee before selecting him, for the specialist expert is the most powerful of all, being generally alone and open to neither control nor dispute.

The sincerity of the soldier to be examined cannot be admitted *à priori*. We must certainly not suspect every man of being a simulator; simulators will not be very numerous; they will be much fewer than might be expected from our knowledge of the ways of those who have met with accidents during their work or in the street.

However, exaggeration of deafness is so tempting to some and so easy to accomplish, that we are quite permitted and even recommended to be always on the defensive against it.

The recognition of a peculiar psychological substratum hinders us from considering the results of our different examinations as precise scientific data; our sole other aim has to be to attain to *approximations* sufficient to classify our men according to their acuteness of hearing from the military point of view.

We are of the opinion, for the same reason, that our injured men furnish us with poor soil for the scientific study of the treatment of deafness; the results can only be uncertain, the conclusions—to say the least—hasty and subject to reserve.

PRELIMINARY INVESTIGATION OF THE HEARING FOR THE SPOKEN VOICE

The systematic examination of the hearing should not be made at the commencement but at the end of

the making up of the medical report. The patient puts himself on the defensive the moment this examination is started, and if he then refuses to listen to us or to understand us, it is all up and we shall never get any answer from him; he will hold on to the acquired result, either by auto-suggestion or by voluntary effort; he will fix his deafness in some way at the degree marked that day, and this will be the same during the whole time of his stay in the hospital.

A preliminary insight into his hearing-power will be arrived at while questioning him and interesting him in the circumstances of the injury, in what followed immediately afterwards, in giving him some easy orders to carry out, which are apparently necessary for the formalities of the investigation or the objective examination.

As head of the aural department, we employed the following technique: the injured man did not come directly to us, but to our secretary, who questioned him and who was placed in such a position as to enable us to see and hear without appearing to do so. We then questioned him; we examined his papers with him; and then we carried out the preliminary objective examination. We at once noted down the maximum distance at which the spoken or shouted voice was heard with one ear or the two during this first interview, so that we possessed from that time an irresistible argument if later on he refused to answer.

We should like to place in this first stage of the examination a test as easy as it is demonstrative and for which we are indebted to one of our colleagues; it consists in testing the hearing while appearing to measure the acuteness of the sight; the man is placed

at one end of the room, the ordinary test-types used by oculists being fixed on the opposite wall; the observer placed between the two at a varying distance from the would-be deaf man, gives him some simple directions such as "shut the right eye, the left, read the third line, step forward, step back, etc.," and notes at what distance he hears.

MEASUREMENT OF HEARING-POWER

It is permissible after these preliminaries to commence the medical report properly so called; we already know whether the injured man presents himself as totally or partially deaf.

The examination should take place in a sufficiently large and quiet locality in the presence of witnesses belonging to the personnel attached to the hospital, but no sick or wounded patient should be present.

This examination does not call for the employment of all the methods for measuring the hearing; it has an aim which is more practical than scientific, namely to be as simple as possible while being sufficient so as not to call for complicated instrumentation or considerable loss of time.

We satisfy ourselves completely for our own part as to the points in the case-paper issued by the Ministry of War, while allowing ourselves some modifications as expressly authorised on this form, according to the views of each experimenter; and we shall now conform to the order in which the different tests succeed each other.

The watch. — We begin with the simplest hearing-test, namely the watch. It is freshly wound

Name and Christian name: .....
Rank and Regiment: .....
Date of injury or illness: .....

Central Service of Oto-Rhino-Laryngology.

of ..... Directed by .....

No. .....
Date of Examination: .....

The Principal of the Centre will judge of the tests to be employed for each particular case.

AUDITORY EXAMINATION.

	RIGHT EAR	LEFT EAR
WATCH:		
Bone Conduction		
Air Conduction		
TUNING FORK Ut³-c (128 v.)*		
Weber		
Rinne (measure & duration)		
HIGH-PITCHED SOUNDS:		
Ut³- c⁴ (512 v.)*		
Galton		
Perception at a distance, transmitted by the nerves of the general system (experiment with fork c⁴).		

HEARING FOR THE VOICE.	RIGHT EAR	LEFT EAR	BOTH EARS
LOUD VOICE;			
Deep Tones {3.4.30 etc. Bordeaux, lambeaux (French) / 4.5.9.52. Tomaro, banana (English)}			
High Tones {6.8.66.10.606. etc (French) / 3.6.16.66. Sea-shell (English)}			
WHISPERED VOICE;			
Deep tones {3.4.30 etc. Bordeaux lambeaux (French) / 4.5.9.52. Tomaro banana (English)}			
High tones {6.8.66.16.606. etc. (French) / 3.6.16.66. Sea-shell (English)}			
Noise Machine			

Characters of the patient's voice. .....

VESTIBULAR EXAMINATION.

NYSTAGMUS

Spontaneous .....
Rotatory {Positive ..... / Negative .....}

Caloric	RIGHT EAR AFTER	RIGHT EAR DURATION	LEFT EAR AFTER	LEFT EAR DURATION
Warm water				
Cold water or cold air (Dundas-Grant.)				

For each side, indicate the duration and after how long it appeared.

STATO-KINETIC TESTS

	EYES OPEN	EYES SHUT
On both feet: Standing (both feet together)		
On both feet: Walking forward		
On both feet: Walking backward		
On right foot: Standing.		
On left foot: Standing.		

GALVANIC EXCITATION

RIGHT EAR ..... | LEFT EAR .....

N.B. The Vestibular tests will only be made if the deafness appears to be of labyrinthine origin.

Objective lesions: {.....
.....}

Diagnosis: .....

Military conclusions: .....

Supplementary Tests: {.....
.....}

Lumbar Puncture: .....

Cochleo-palpebral reflex: .....

The Principal of the Service:

Detailed observations may be written out on the back of this sheet

up and applied on the mastoid process and on the temple, and we note whether or not it is heard by bone conduction.

Air conduction is investigated in the following way : the subject is seated, with the eyes closed and the opposite ear stopped up ; the watch is at first held at a distance and then approached by degrees to the ear being examined, following a perpendicular axis or sagittal plane ; we note the distance at which it is first heard ; the test is repeated several times for each ear.

This test is within the reach of everyone, but *in our opinion is of no value.* We attach no importance to the absence of bone-conduction seeing that it cannot be controlled.

The absence of air-conduction cannot be controlled either. Defective air-conduction would be, we may be told, difficult to simulate, as the subject has his eyes closed and does not know the distance of the watch; he exposes himself, if he is desirous of deceiving us, to discrepancies which prove his bad faith. This argument is not valid, for the patient has only to wait each time until the " tic tac " seems very loud to him in order to be able to deceive us sufficiently and regularly.

In practice we have noted that deaf people hear the watch particularly badly ; we are not the only ones to note this. Moure has written : " A very interesting fact to be noted in soldiers is the difference which exists between air-conduction for the watch and for the spoken voice. The patient who hardly perceives the ' tic tac ' at from 1–20 cm., hears, on the contrary, the ordinary voice several metres away, often from 4 to 5 and even further than that."

We believe that this peculiarity of war-deafness is attributable to a certain psychological condition of the injured man rather than to anything else, and we repeat that non-perception or poor perception of the watch signifies nothing.

Tuning-fork.—Tuning-forks help us to establish data of considerable importance. They will contribute to measuring the acuteness of the hearing by air-conduction; they will give information as to the extent of bone-conduction for sounds; they will permit finally of comparison between the two modes of perception for each ear.

The study of the *perception by air-conduction of definite sounds* indicates the degree of the lesion, and to a certain extent its situation in the middle or internal ear, and even in both if they are affected simultaneously.[1]

Deep-toned tuning-forks.—For examining the *perception of deep tones* we use Gradenigo's tuning-forks of 32, 64, and 128 double vibrations per second, the weight on which, while being opposed to the formation of harmonics, allows, thanks to the index inscribed on its external surface, of measuring the

[1] We know that any involvement of the middle ear affects the perception of low-pitched sounds by air-conduction, and that a labyrinthine lesion, on the other hand, affects especially the perception of high-pitched sounds. In the former case it is the lowest-pitched sounds which cease to be heard in the first place; the lower limit of perception is raised, so to speak, proportionally to the degree of the lesion; in the second case it is the perception of the highest pitched sounds which disappears first, and the upper limit is lowered as the lesion increases. The ascertainment of a disturbance of hearing for sounds situated at one of these extremities of the normal scale localises to a certain extent the lesion in one or other part of the ear.

This comparative study of the different tuning-forks constitutes a useful, but not indispensable, test. We may quite well content ourselves with the two tuning-forks indicated on the ministerial form.

amplitude of the vibrations and consequently of examining each ear with a sound of the same intensity. This index consists of a black triangle on a white background; it is divided into four equal parts by three black transverse lines. If the prongs of the tuning-fork are made to vibrate vigorously two black triangles separated by a clear space are seen at first. As the amplitude of the vibrations diminishes these two triangles approach one another and soon overlap by their inner margins; then there is to be seen

FIG. 11. FIG. 12.

Gradenigo's tuning-fork. Fig. 1, the index in motion. Fig. 2, the index in repose.

between the two original triangles a third *blacker* one, the apex of which reaches the lowest line, then the two upper lines, and ends by becoming blended with the index-triangle when the tuning-fork ceases to vibrate.

For this test, the tuning-fork being set in vibration, we wait till the apex of the little median triangle reaches the lowest line, and then place it opposite the entrance to the external auditory meatus and count from this moment the duration of perception. We investigate by this means each ear separately

with each of the three tuning-forks and write down the results.

It is not necessary, during this examination, to stop up the opposite ear; the deep-toned sonorous waves only extend a short distance and cannot reach the other auditory meatus.

High-pitched tuning-forks. Galton's whistle. Monochord.—Examination of the *perception of high-pitched tones* is made either with tuning-forks, Galton's whistle, or better still, with Struycken's monochord. *The use of high-pitched tuning-forks* is not devoid of inconvenience; a complete series such as Edelmann-Bezold's is costly and does not attain to the uppermost limit of sounds normally perceived by the ear. The official form includes only the tuning-fork c^2 (ut^4). To this is added Galton's whistle, or better still, Edelmann-Galton's, an apparatus which affords a continuous series of sounds from 6,000 to 30,000 vibrations.

FIG. 13.—Galton's Whistle.

We prefer for an acoumetric examination of the labyrinth Struycken's monochord, a simpler and more exact apparatus and which replaces all preceding ones.

Struycken's monochord consists of a steel wire extended between the two curved extremities of a graduated rod; one of these extremities, which is widened, constitutes the fixed point of attachment of the wire; the other supports a regulating screw by which the wire can be stretched more or less tightly

Lastly, on the ruler is a sliding weight which limits the vibrating portion of the wire.

The instrument must be arranged in such a manner that when the slider is placed exactly on the figure 44 of the graduation in centimetres, the wire set in vibration by a blow from a little wooden hammer,

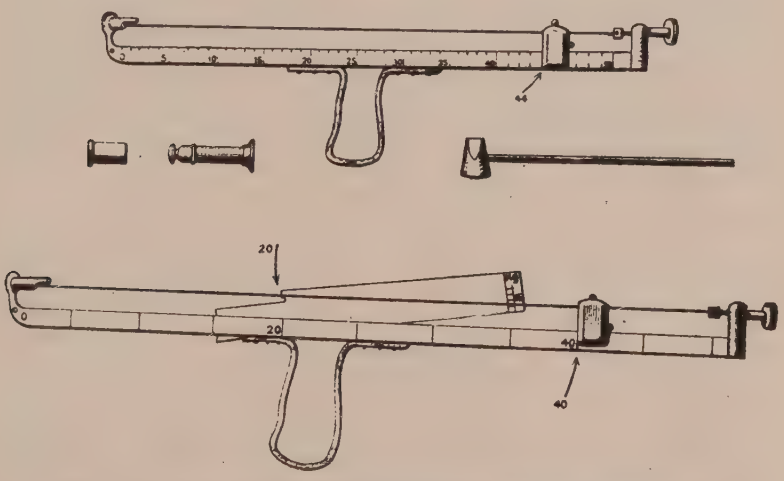


FIG. 14.—Struycken's Monochord; degree of tension of the wire.

gives the la^3 (a^1) (435 double vibrations); a tuning-fork of the same tone, contained in the case, serves as a standard; the wire is tightened or loosened until unison is obtained.[1]

According as to whether we use the transverse

[1] Struycken has invented an ingenious method of control; instead of determining the sound emitted he measures the tension of the wire. The slider being at the division 40 he places the controlling apparatus on the monochord in such a way that the upper support rests on the wire directly above the division 20 of the centimetric scale. the lower support projecting on to the lower border of the monochord. The wire must be tightened or loosened so that it covers the division 25 written in red at the other extremity of the measuring apparatus.

or longitudinal vibrations of the wire, a continuous series of pure sounds from 435 to 24,000 vibrations is obtained.

For testing, the rounded end of the apparatus is placed 1 cm. from the auditory meatus and the wire is struck with a little wooden hammer; the sound emitted is la^3 (a^1), 435 V., if the weight is at the division 44. If the latter is placed at the division 22 the sound obtained is la^4 (a^2), 970 V.; at the division 11 the sound emitted would be la^5 (a^3), 1,940 V.; at $5\frac{1}{2}$, 3,880 V. would be obtained, etc., the number of vibrations being inversely proportional to the length of the vibrating wire.

When above 5,000 V. it is the longitudinal vibrations of the wire which are used; it is then sufficient to rub it lightly in the direction of its length with a tampon of felt specially moistened with carbon tetrachloride or, failing that, chloroform. A second graduation in Roman figures inscribed on the upper border of the rod indicates at what point the slider should be placed to obtain 6,000 V., 7,000 V., etc., up to 25,000 V.

The test is made once or twice and the maximum number of vibrations perceived with each ear is noted.

In reality, testing the high-pitched tones only gives accurate results in bilateral labyrinthine deafness. In unilateral deafness the stopping up of the auditory meatus of the opposite side does not shut out the sound from that ear; it is necessary to use a "deafener" (*assourdisseur* or "*noise-machine*") in order to totally eliminate it, but the noise of the *assourdisseur* extending by bone-conduction to the ear being examined, detracts from the precision of the examination.

On the other hand, we possess in this a means of very strongly suspecting simulation of unilateral deafness if the man being examined pretends not to hear the tuning-fork c^2 (ut^4) vibrating in front of the ear which he says is deaf, whilst the good ear is left open.

Schwabach and Rinne's tests.—*The measuring of bone-conduction* goes by the name of Schwabach's test; it serves for estimating the hearing-power of the internal ear. It is of the utmost importance for us who see so many cases of labyrinthine concussion.

The comparison of the bone- and air-conduction of each ear is called Rinne's test; we combine it, so to speak, with the preceding one so as to read at a glance: how the ear perceives the tuning-fork by the air, how the isolated internal ear hears the tuning-fork vibrating on the bone; the relation between these two numbers informs us as to whether the lesions concern the conducting apparatus or the percipient apparatus most—the middle ear or the labyrinth.

As for Weber's test, we shall see later how useful it is.

The tuning-fork used is c (ut^2). The observer holds it by its foot and strikes the flat end of one of its prongs on a resistant immobile non-metallic object, wood by preference; he strikes without violence but with resilience; the best way is to let the tuning-fork fall by its own weight in order to obtain a duration of vibrations which is practically always identical.

The observer sets his watch going at the same moment as he strikes, and he then places the foot of the vibrating tuning-fork, quite flat, on the base of the

FIG. 15.—The observer strikes the tuning-fork and looks at his watch.

FIG. 16.—He waits a few seconds before putting the tuning-fork on the mastoid.

FIG. 17.—The patient announces the cessation of hearing. The observer looks at his watch.

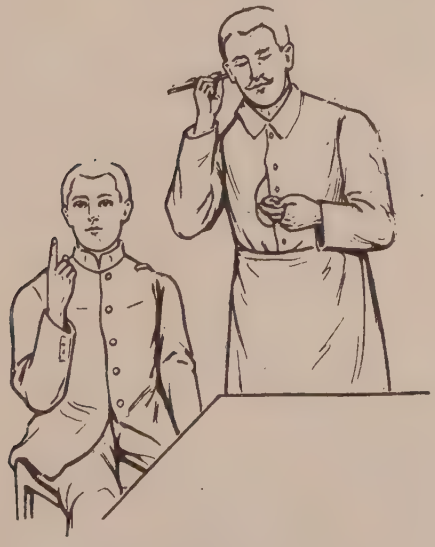


FIG. 18.—The observer calculates how much more his own perception is than that of the patient.

mastoid process; the patient announces the cessation of the auditory perception the moment this takes place; the duration of the perception is noted in seconds. Should this figure be very low, we register it such as it is, after checking it by a second identical test. Should the number of seconds be greater, the experiment is repeated in the following manner: we strike the tuning-fork and set the watch going as before, but we let the tuning-fork vibrate in the air and wait, before placing it on the mastoid, until three-quarters of the time formerly marked down has passed; only then do we place the foot of the tuning-fork on the mastoid process and stop the watch at the exact moment when the patient says he ceases to hear it.

The number of seconds indicated by the watch gives the real degree of acuteness of hearing for the tuning-fork by bone-conduction; it is most often markedly higher than the first test. The reasons of this difference are: (1) physiological, (2) psychological. The physiological reason is known to all; it is fatigue of the nerve; the psychological (Gosset) is peculiar to the medical survey. Our man may have thought it well, at the time of the first examination, not to hear the tuning-fork for more than 15 seconds; you start the test again; he does not suspect that the force of the tuning fork has been expending itself while it has been allowed to vibrate in the air, and he thinks it reasonable not to simulate a perception lower than 15 seconds.

The measurement of the bone-conduction of one ear is accompanied by the possibility of making the greatest errors; this arises from the difficulty of eliminating in certain cases the hearing of the ear not under examination.

The principles of the problem are as follows: given two internal ears almost equivalent, the vibrating tuning-fork on the right mastoid process transmits its vibrations across the cranium to the two internal ears, but the sound is perceived much more loudly by the right ear, as excitation of the left acoustic nerve does not reach the field of consciousness and is practically negligible.

Given two internal ears very unequal, the right very bad, the left normal or nearly so. I set the tuning-fork vibrating and place it on the right mastoid process; the patient listens, but *à priori* I cannot know if he hears with the right or the left. I shall check this by stopping up the right ear as soon as the patient ceases to hear it; if the sound re-appears in the right ear it shows that it was perceived by the right cochlea; if not, I repeat the experiment, stopping the left ear, and the sound re-appears in the left ear, the tuning-fork still vibrating on the right mastoid process; the conclusion is in favour of the left cochlea.

I must then eliminate the hearing of the normal left ear entirely if I wish to measure the hearing capacity of the badly affected right internal ear, and for that I shall use a "deafening" apparatus for the left side.

We shall later on describe Lombard's *assourdisseur*, which is most practical. It has something of a drawback, for, by transmission through the skull, it deafens not only the ear that we wish to eliminate, but also to a certain extent the one being investigated.

Let us suppose again that the right ear is for functional purposes destroyed and the left ear normal; I place the tuning-fork on the right mastoid process;

the patient says, "I hear it." As the other tests and the antecedents will have made me distrustful of this false perception, I verify it by the use of the noise-machine to the left ear, and I ascertain that in reality the right internal ear hears nothing. The right ear would not, of course, have heard the tuning-fork by air-conduction. Lermoyez and Hautant have given the name of *false negative Rinne* to the result (apparently paradoxical) of suppression of air-conduction with preservation of bone-conduction in cases of unilateral labyrinthine deafness when the hearing ear is not closed by the noise-machine. We shall see at the end of this article that this *false negative Rinne* constitutes a real test of sincerity.

Summed up this is very simple and might perhaps be stated in a few lines; the reader will excuse the length of this digression; we wished to be as clear as possible as the question has appeared to us to have been sometimes made obscure and complicated, as if on purpose. Let us remember when we are examining one ear always to eliminate the hearing of the other.

Let us return to Schwabach's test; we have noted down in seconds the bone-conduction of each ear for the tuning-fork *c* (ut^2). Is this sufficient? By no means. What is it we wish to know and note? The patient's degree of deafness. You would read later on in his case-paper, "Schwabach=10," which would tell you nothing, for as you do not know the tuning-fork, or with what force I struck it, you do not know—in a word—how the patient would have heard it if he had not been deaf. Here is indeed a problem. I must then, when the patient ceases to hear it, apply the tuning-fork on the mastoid

process of my own presumably sound ear and note how many seconds I hear it longer than he does; I note it down; then alone can we know if the man was slightly or markedly deaf.

This comparison between the patient's and the observer's ear is not strictly scientific, but it is sufficient for practical purposes.

The long commentaries which we have devoted to the study of bone-conduction for the tuning-fork *c* (ut^2) will permit of dealing more shortly with "air-conduction."

The tuning-fork, struck as before, is held with the end of its prongs opposite the entrance to the auditory meatus; we note down the duration of the perception and compare it with that of the normal person; we allow the tuning-fork to vibrate a little way off before bringing it close to the meatus, and we even withdraw it and approach it alternately whilst the ear is listening to it, so as to avoid fatigue of the nerve.

This done, we possess four data, the duration of perception of the vibrating tuning-fork on the mastoid process of the ear being examined and on that of the normal person, and the two corresponding amounts for audition by air-conduction.

We formulate this quadruple result as follows :—

$$\text{Tun. F. } c\ (ut^2)\ \text{R. Ear} \begin{cases} \text{air } x'' \text{ instead of } n'' \\ \text{bone } x''_1 \text{ instead of } n''_1 \end{cases} \quad \text{L. Ear} \begin{cases} y'' \text{ instead of } n'' \\ y''_1 \text{ instead of } n''_1 \end{cases}$$

Is not the information thus furnished more complete and more precise than the classical formulæ :—

Schwabach + or —
Rinne + or — ?

Weber's test.—Everyone knows of what it consists; the vibrating tuning-fork *c* is applied to the forehead; it is localised to the side of the deaf ear if the deafness is due to a lesion of the conducting apparatus (middle or external ear); it is localised to the side of the good ear when it is the cochiea of the deaf ear that is affected.

We shall not dwell on the psychological difficulties which are experienced with this simple test. We all know that a person of good faith and even intelligence nearly always begins by localising the sound in the good ear, even if he really hears it in the deaf ear as a result of involvement of the middle ear; he is so persuaded that his ear is deaf that the auto-suggestion is inevitable. The conclusion arrived at from this is that while guarding against dictating the answers to the patient, the experiment should be repeated a certain number of times asking him to be careful of his answers, until a conclusive result can be registered.

Weber's Test, when decisive, gives some valuable information for the medical report.

We quote the following cases as examples of this: (1) Cicatricial otitis or old-standing otorrhœa, without any sign of recent injury; the man proclaims himself deaf since an alleged concussion. Lateralisation of Weber to the deaf ear shows the absence of a traumatic labyrinthine lesion; the deafness is probably of old standing and is due to lesions of the middle ear.

(2) Recent perforation of the tympanic membrane from an explosion; Weber's test is lateralised to the good side; we conclude that the labyrinth has been injured at the same time as the membrane; prognosis with regard to the deafness is reserved.

If the Weber is lateralised to the injured side, the labyrinth has not been perceptibly affected ; and the prognosis with regard to function is more favourable.

(3) Recent concussion, with slight or no traces of injury to the right tympanic membrane ; marked unilateral deafness on the right side ; Weber localised decidedly to the left, sound side ; we conclude there is concusson of the right labyrinth. But how shall we check the patient's statements ? If he is not forewarned, Weber's test furnishes us with the means of entrapping him.

The tuning-fork is set vibrating on the vertex ; it is stated to be heard by the left (the sound) ear. I then stop up this left, sound ear ; the honest patient will declare that he hears it better than before ; the simulator, if *not forewarned*, declares that he no longer hears anything. Such a result is actually impossible, the bad faith will be evident even to the eyes of the layman.

HEARING FOR THE SPOKEN VOICE

Loud voice.—All the other hearing tests are in a way only the preliminaries for the medical report ; examination of the hearing power for the human voice constitutes, on the other hand, the chief part and alone dictates the conclusions.

In fact, what does hearing for the watch or the tuning-fork matter ? We must state whether the soldier hears well enough to understand orders, whether the injured man can communicate with his fellows and to what extent.

This test has already been roughly made at the beginning of the examination, and we will not revert

to the importance of the acquired results. We keep them in our memory when we are about to carry out the systematic investigation.

This test should not be carried out haphazard but according to a strictly regulated method.

We no longer ask the patient to answer the questions put to him or to execute orders. We ask him to repeat syllables or words; we shall in this way know with greater certainty whether he has really heard, and we can then recognise in a more exact way the defects of his hearing.

The voice employed is the ordinary conversational voice, well articulated. Those with extreme deafness require the shouted voice.

Unfortunately, the intensity and the ease of comprehension vary with each observer. There result, therefore, great digressions with the same patient, according to the examiners. This drawback, which is enormous in regard to scientific research, may be ignored in the case of medical reports for which approximate results are required. Although it would be dangerous to determine the effects of treatment of deafness by the distance at which the patient hears the loud voice of different persons before and after certain periods of such treatment, yet it is permissible to state that a soldier who can hear the loud voice of one of us at from 4 to 5 metres, is fit for combatant service.

The sounds uttered by the loud voice may be meaningless syllables, any chance words or words chosen beforehand.

The man to whom we are speaking not only listens with his ears but with his eyes and brain. These latter organs do not actually interfere if the

sounds reach the ear with sufficient force for it to register *all* of them without effort. But the sounds which make up human speech differ much in intensity ; an ear, interrogated to the extreme limit of its auditory power, perceives certain sounds, not others ; the patient, however, quite understands the word and the phrase in their entirety because he guesses what he does not hear, in the same way as we can reconstruct an inscription of which some letters are missing. In addition, the deaf man has unconsciously acquired the habit of watching his questioner ; he lip-reads some of the sounds that he does not hear ; the fact is an everyday occurrence ; a partially deaf man understands much less in the dark ; he likes to follow with his opera-glasses the movements of the faces of the actors.

We must, therefore, eliminate sight and intelligence in the scientific investigation of the deafness ; this is easily arrived at, in the first place by the respective positions of the doctor and patient, or better still by the closing of the patient's eyes, and in the second place by the utterance of disjointed syllables : lah, fah, vu, po, ba, etc. This is how professors of deaf-mutes proceed when they undertake the auditory re-education of a deaf subject.

This method further enables us to analyse the defects in the patient's hearing, and shows that certain sounds are in general better heard than others, thus furnishing the means of drawing-up tables of increasing difficulty.

But in spite of all these advantages, this method, so valuable for scientific research, is not suitable for examinations for actual medical reports ; it is not easy to get a deaf man or a simulator to repeat even

such words as he knows ; it would become a Herculean task if we tried to make him repeat disjointed syllables ; he only answers what he wishes and how he wishes ; we risk being led into the most fantastic results. Why ? Because all check is wanting, whereas you would be able to call your man quickly to a sense of the realities if he refused to repeat well-known words at a distance at which you know perfectly well that he understands the spoken voice.

We consider then that we must take care not to eliminate the rôle of the brain. Like Halphen [1] and many others we choose words most easily understood and guessed by all, such as numbers, for the results must be comparable the one with the other, and such words as "lambeau," "Vichy," etc., which seem to us familiar and easy to repeat, are for a peasant from the fields almost unused terms which he will hesitate to pronounce.

"Six," "Sixty-six," "Seventy-six," etc., will serve for measuring the audition for high-pitched sounds. "Forty-four," "Ninety-two," etc., for deep tones. The patient is seated at the end of a quiet and sufficiently long room, on the walls of which the yards or feet are marked off so that the distance between the examiner and the examinee can always be ascertained.

A trained nurse covers the patient's head with a cloth so that he may not know at what distance he is from the observer at the time of the examination ; she has an important work to do, namely that of closing the ear which is not being investigated ; the telephone *assourdisseur* is likely to deafen the two ears and to make an impression on the patient ; simple closure with the finger or cotton wool moistened

[1] *Des lésions traumatiques de l'oreille interne, Thèse*, Paris, 1910.

with glycerine is open to the greatest errors. We have recourse to a manœuvre which consists of rubbing the auricle of the ear with the palm of the flat hand. Anyone can try this mode of obliterating the hearing on himself to see how efficacious it is.

The observer, placed in a line with the auditory meatus of the patient who is seated sideways, repeats in a loud voice various numbers, while changing his position by retreating and advancing; but he walks noiselessly; thus, the injured man is quite ignorant of the distance at which the sound is emitted.

If he is in good faith, the test is easy to make; we note the maximum distance at which each group of numbers is heard clearly. If he is simulating, he finds himself in a very embarrassing position; he commences by repeating nothing; it is then that the attentive nurse puts on the psychological catch; she questions him; she explains to him how unlikely it is that he should have become suddenly quite deaf; he then consents to repeat what he hears, and the man who did not hear "three" or "four" at one yard begins to understand at five or six yards and more.[1]

FIG. 19.—Position of the patient for the test of the loud voice.

[1] The deafening of one ear with the *assourdisseur* influences the other; we should stop it and be content with closing up the ear when the extreme distance of comprehension is arrived at, if we wish to obtain an exact measurement.

We have insisted on these apparently futile details, but they are very important for us; the medical report offers much less guarantee when the test of the voice has been practised with the patient's eyes open, for he will then himself measure his auditory power according to his own desires.

Whispered voice.—Investigation with the whispered voice presents a characteristic of preciseness which places it, from the scientific point of view, far above the practical investigation with the loud voice. We agree to this willingly. We register the results of this test with great interest in the case of a deaf man who is sincere; but we do not know how to eliminate deceit, and, practically speaking, the test is not of much value for a medical report; very few injured men consent to listen to the whispered voice, or they will perceive it only at a distance which they know to be very short, even when their eyes are closed. Nevertheless, the experiment will always be attempted; the residual air will be used according to the classical data; it is useless to dwell further on this. The ear not being examined is eliminated by simply stopping it up with the finger.

COCHLEAR REFLEXES

A. **Cochleo-phonatory reflex.** — *Lombard's Test.* — Everyone knows that extremely deaf men do not speak in a normal voice. All do not shout "like deaf men"; many even talk in a faint muffled voice with no ring in it. Not hearing themselves speak they have lost control of their vocal utterance; the same individual may begin a conversation in a very low

voice and an instant later shout noisily, quite unconsciously.

The normal man who desires to be understood by others, modulates his vocal intonation so as to hear himself speak ; we talk more loudly in a moving train than in a quiet place ; this adaptation is unconscious ; it is not a manifestation of will ; it is a reflex action.

The investigation of this reflex permits us, under certain conditions, to determine the auditory acuteness.

The classical authors contrast the normal voice of a really deaf man with that of the simulator which has not altered. But such an observation does not furnish precise data for a medical report.

The test suggested by Lombard is, on the other hand, productive of practical results. It is based on the following principle : total and sudden artificial deafening of both ears in a normal subject produces a sudden and unconscious raising of the speaking voice ; this voice-raising stops suddenly at the same time as the " deafening."

If this same manœuvre is performed in a case of extreme bilateral deafness with both labyrinths involved, no modification of voice is produced for the reason that we cannot " deafen " anyone who already hears nothing.

The noise-machine applied to one ear in a normal subject brings about only imperceptible raising of the voice, because the other ear is sufficient for the production of the reflex regulation of the voice.

In a case of unilateral labyrinthine deafness the application of the noise-machine to the good ear has the same result as when both ears are deafened in the normal person ; the patient finds himself suddenly

quite deaf and he shouts. Of course the application of the noise-machine to the deaf ear has no effect.

Lombard's apparatus is the ideal *assourdisseur*, or noise-machine, for this test. It consists of two

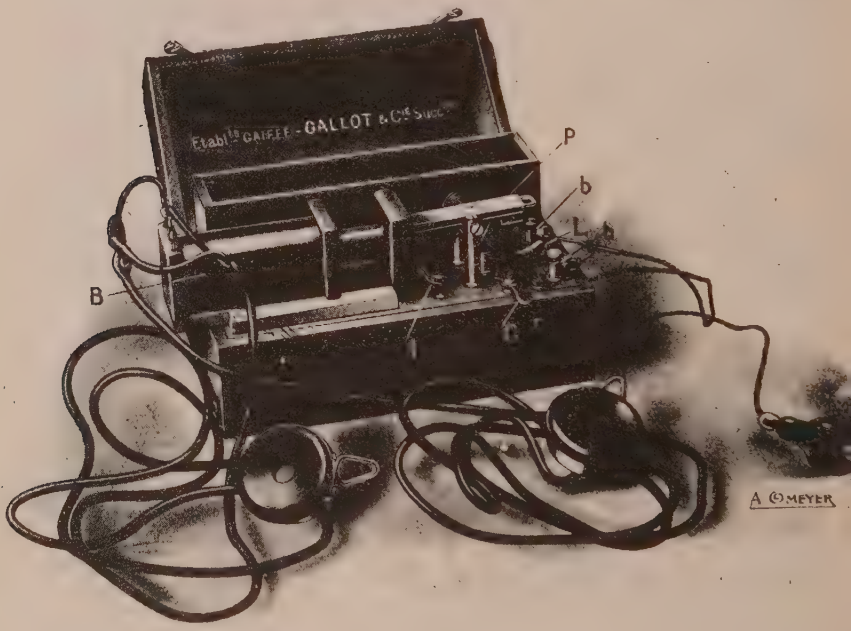


FIG. 20.—Dr. Lombard's *assourdisseur* (noise-machine or deafener) (Gallot & Co., makers).

bb'. Flexibles going to interrupting push-switch.
P. Pallet (interrupter).
L. Lever controlling the number and the amplitude of the oscillations of the pallet P.
C. Commutator closing the circuit of the battery on the inductor.
B. Induced coil, the power of which depends on the distance to which it is pushed on to the inductor.

telephone ear-pieces into which the current from an induction coil enters, an electric current having been thrown into this latter. Lombard's arrangement is

perfect; some have given themselves the pleasure of varying it without improving it; for our part we simplified it as far as possible in 1915; we connected our telephone ear-pieces directly to the two poles of the galvano-cautery of a Gaiffe transformer; the apparatus thus constituted is adjustable; it can be started and stopped suddenly, these actions being dependent on the interruption of the transformer. There is one indispensable precaution, namely, that the length of time of vibration should not be prolonged for fear of heating of the transformer. However, the noise produced is not so considerable as in Lombard's form, which is still the best.

The way of carrying out the experiment is of the simplest: the patient is seated; the telephone ear-pieces are placed to the ears; the patient begins to speak; the current is started; he either raises his voice or he does not do so; the current is then cut off.

The experiment is all the more conclusive when the patient does not resist, and the more he is occupied by what he is saying the less he is on the defensive. The most favourable condition is obtained when the man relates the history of his campaign or recites something from memory; the mental effort occupies him entirely, and he is in a state of inertia favourable to the production of the reflex; if he will not narrate or recite we get him to read aloud; the conditions are, however, not so good; if we cannot get him to read fluently, we ask him to count; every man knows how to count; he must, however, count loudly, quickly, and without stopping on any pretext whatever.

This "deafening" process, much used by us, was

greatly dreaded by the exaggerators under our care; they looked upon it as a veritable "Irish footpath" interposed in a series of obstacles to be overcome. They tried their best to avoid it.

Some flatly refused to submit to it; they professed that the vibrations caused them an amount of discomfort which it was impossible to overcome. We, therefore, made a rule of practising the test very soon after the arrival of the injured men and in such a way that they were not prejudiced against it. Moreover, we recognise that the sudden use of the noise-machine to one ear or the two together may produce a disagreeable effect which explains why the patient who has not been warned stops speaking; this "surprise" is especially painful to a man suffering from concussion, and its effect is shown by an odd inhibition; one of our comrades suffering from concussion of one ear was "deafened" while he was reciting one of La Fontaine's fables; when the noise-machine was applied to the good ear very marked voice raising was produced; when applied to the affected ear which was only partially deaf, he experienced a disagreeable sensation as well as, at the same time, loss of memory, so that he could not remember the fable; this disturbance only lasted an instant; it is, therefore, indispensable to accustom the injured man to it before commencing the experiment; the telephone ear-piece is applied while vibrating gently at first and then more loudly, and he is asked whether he can hear the noise produced as if his hearing were being tested; he often confesses to hearing it very slightly and so does not refuse finally to tolerate it during phonation.

Certain subjects who are not deaf and are known to have good will, do not raise the voice while the

noise-machine is being used; these are people who ordinarily speak in a dull toneless voice and who talk, as it were, within themselves; we must ask them to make the necessary effort so that they can be heard by anyone a few yards away.

Others do not raise the voice because, being forewarned, they try with all their energy not to do so; if we stop the noise-machine suddenly they lower the voice all at once; the reflex has, therefore, acted; it is proved that they hear themselves speak.

Again others do not raise the voice because they begin by shouting with all their might; it is for us to discern whether this tone of voice is habitual to them or whether it is put on.

The "noise-machine" test when practised with care gives invaluable results; it has the great advantage of being demonstrative even for the layman.

We must not expect more of it than it can give; a subject whose cochlear and phonatory centres react in a normal manner may not have, for all that, perfect hearing; he may even be dull of hearing, but he has not, to a certainty, a destructive lesion of the internal ear with extreme deafness. This test is of value for all alleged labyrinthine deafnesses due to direct or induced traumatism, to a projectile or a displacement of air, the most frequent cases for medical reports.

B. **Cochleo-pupillary reflex**—Halphen describes in his thesis Ostino's cochleo-pupillary reflex; under the effect of perception of the tuning-fork the pupil narrows and then dilates. Halphen denies all practical value to this unreliable and generally feeble reflex, which cannot be determined without a special apparatus.

C. **Cochleo-palpebral reflex.** — Gault, head of an otological clinic, has drawn attention to this reflex which is much more reliable than the preceding one; it depends on the fact that auditory perception of a sudden noise causes contraction of the orbicularis palpebrarum of the same side.[1]

The subject is seated facing a window; the observer places himself between the patient and the window in such a manner that the patient's face is well illuminated.

A *sudden* but slight noise is produced *unexpectedly*; if heard it provokes a slight winking movement, chiefly disclosed by an examination of the tips of the eyelashes, truly a magnifying index to the palpebral movement.

[1] The cochleo-palpebral reflex has lately been the subject of numerous publications.

Molinié, who has described it very fully, considers it an exaggeration of the normal reflex of auditory accommodation. The normal route of this reflex which brings about contraction of the stapedius muscle follows the acoustic nerve, the cochlear nucleus of the bulb, the nucleus of the seventh pair and of the facial nerve. If the sonorous impression is severe, the motor excitation which it sets free and which is too intense to be confined by the few fibres going to the nerve of the stapedius, invades the neighbouring fibres and reaches with them the orbicular muscles of the eyelids. A still more intense sonorous excitation gives rise to contraction of different muscles of the face, the head, the nape of the neck, and even the whole body. Is it quite true that such an intense reaction can be the effect of a simple exaggeration of a reflex of auditory accommodation? We should rather consider the cochleo-palpebral reflex as a partial manifestation of a reflex of general defence of the organism which is observed to follow an *unexpected sensorial impression*, sonorous, luminous, tactile, etc.; hence the importance of the element of surprise for the determination of the reflex.

Whatever be its nature, the contraction of the orbicular muscle of the eyelids indicates that the auditory impression has indeed been received and transmitted to the centres. As this impression has no other route of penetration except the auditory nerve the reactionary manifestations consecutive to the auditory impression are a witness to the anatomical functional integrity of the labyrinth and cochlear nerve. We have, therefore, in these provoked reflex manifestations, a means of investigating the auditory nerve (Molinié).

Simple clicking of the fingers is sufficient for a sound ear. We use louder and louder noises until the reflex is produced if the subject is partially deaf, using, for example, those produced by the blow of a key on a metal lid, or a bell, the ear not under examination having been carefully stopped up by a plug of cotton wool moistened with glycerine a few moments before starting the test for the reflex. But it must be remembered that the reflex will wear itself out ; it must only be provoked *once* at each examination and *always unexpectedly*, as, for example, during the objective examination.

We need not insist on the simplicity of such a test and on the evidence of its results.

It will become still more exact and more valuable when we possess an apparatus which produces an identical noise, accepted by all and graduated so as to fix the minimum of perception necessary to provoke the winking movement.[1]

However, the rôle of surprise is such that there will be great advantage in the noise-producing apparatus being as simple as possible so as not to attract in any way the attention of the man under examination.

TESTS OF RELIABILITY

The notes of the hearing-power having been taken, we must draw our conclusions. We are not here making a scientific investigation but a medical report ; we must, before arriving at a conclusion, know how

[1] R. Foy has attempted this by modifying Lombard's apparatus, which he uses not as a deafener but as a source of sound (*Presse Médicale*, 1917).

to estimate the sincerity of the subject. Certain tests have already given us useful information from this point of view; they are, however, insufficient for difficult cases.

We will review the different problems which the expert must determine.

Deaf-mutism.—The man hears nothing; he does not speak; the making of a medical report is almost impossible; however, the cochleo-palpebral reflex here shows its great value. If this is preserved we shall then know that the deafness is of functional rather than organic origin.

Complete bilateral deafness.—The man speaks, but he does not hear.

Cases of total bilateral organic deafness due to a double labyrinthine lesion are very exceptional. We do not profess, however, to deny their existence.

Traumatic hysteria and simulation may have this same syndrome.[1]

Simulation is really painful to an individual with any intelligence, unless he succeeds in making us believe that he has acquired lip-reading.

The *minus habens*, the illiterate, suffers much less from moral solitude; he also makes a greater stand against the expert examiner, the absence of means of communication between him and the examiner considerably reducing the range of tests.

The attitude of the subject under examination furnishes the first element for distinguishing between organic and functional deafness; we have described that of the hysterical man and simulator

[1] In this chapter on Medical Reports we do not distinguish true simulation from the unconscious simulation of the hysterical man; the means for the diagnosis have been set forth in the chapter on Simulation.

as being opposed to the habitual attitude of the really deaf.

We must not count on the supervision of male or female nurses for taking the simulator by surprise when in conversation with a comrade, for he mistrusts everyone and everything.

We shall on rare occasions succeed in convicting him by taking him by surprise ; bringing the examination abruptly to a close, we say suddenly in a natural voice, "Get up," "That's all"; he gets up and is detected ; or else we call him back unexpectedly, or let a piece of money fall on the ground, and he turns round. All this is, however, as a rule, useless trouble.

The surprise is greater if the attention is very quickly drawn towards a particular point.

Chavasse and Toubert stop examining their patient ; they undertake the treatment of the so-called deafness by catheterisation of the Eustachian tube. This little intervention tickles the pituitary membrane disagreeably ; at the time of the sitting the order to rise or turn the head is quietly given ; if this order is carried out it shows that hearing is preserved.

However, none of these means of estimation are equal to the cochleo-phonatory and the cochleo-palpebral reflexes. The latter is easily effected, but it must be sought for quite unexpectedly to the patient.

"Deafening" by means of the noise-machine sometimes presents, especially among those who are illiterate and "pretend to be idiots," so much difficulty that we hesitate about drawing a conclusion from it. When the test succeeds it is decisive.

There still remains an extreme measure which we have never had to employ, namely, to chloroform the patient and question him during the intoxication (Pasquier and Halphen). It would be less risky to surprise him in his sleep in the morning and to wake him up by speaking or the noise of ringing.

A new and valuable addition to these tests is furnished us by checking the lip-reading in injured men who understand this language.

We wish first of all to establish the fact that we believe in lip-reading on the part of totally deaf men. One of us (Bourgeois) was among the first (May, 1915) to introduce it into his department and to note some conclusive results. He has also seen some remarkable successes obtained by the professors of the Institution for Deaf-mutes in Paris.

It is the right of every deaf man that we should give him this important relief in his infirmity ; further, we owe it to the dull of hearing whom we have given up hope of improving. But this instruction is a double-edged weapon ; it constitutes, if we do not take care, a marvellous opportunity for the simulator. To feign total deafness is extremely painful for anyone who has the least intelligence. How agreeable and elegant it is for him to learn in a few weeks to converse as in the past with his fellows! He is a marvellous subject, the pride of his professor whom he leaves with a discharge paper, adorned with a gratuity and universal admiration !

The possibility of such an abuse calls for serious checking which takes the form of a new test for the sincerity of the deaf men. This method had its origin in our clinic, having been invented by our collaborator Gosset, and, we may say, at our instigation, for we

have always manifested our astonishment at the rapidity and perfection of some of the successes. We have ourselves perfected this method of control.

M. Gosset's three experiments were published by him in the *Progrès médical* of Feb. 5, 1916.

The first is based on the fact that "ah" can be said with the lips in the position usual for articulating this vowel, but that it can be also emitted with almost any movement of the mouth and, to be particularly noted, that used for the sound "ē"; the normal positions for "ah" and "ē" are very different, of which anyone may assure himself if he tries it in front of a mirror.

We set about the test in the following manner:—

1st. By saying *ah*, *o*, *ā*, *ē* (English), *u* (French) in the usual way, the patient repeating the vowels as they are uttered.

2nd. By emitting the sound *ah* while articulating as for the sound *ē*.

The deaf man who reads *ē* repeats *ē;* if he is uncertain he hesitates and answers nothing; the simulator says *ah;* it is a simple and conclusive proof. That from all the vowels the subject should choose *ah* of which the articulation is so different from *e* is because he heard *ah*, in fact, because he could really hear.

The second test consists in emitting any vowel in a slightly raised tone, then more loudly, then very loudly. The deaf man who is guided only by the movement of the lips repeats in the same tone; the simulator, guided by his hearing, lowers and raises the tone as does the professor; this would certainly be a proof that he hears.

Lastly, Gosset articulates without emitting any

sound; the deaf man reads and repeats; the other remains silent.

This last experiment is less conclusive than the others, because we are not sure that the movements of the lips are absolutely identical when the sound is actually pronounced and when only articulated. The second test rarely succeeds. It

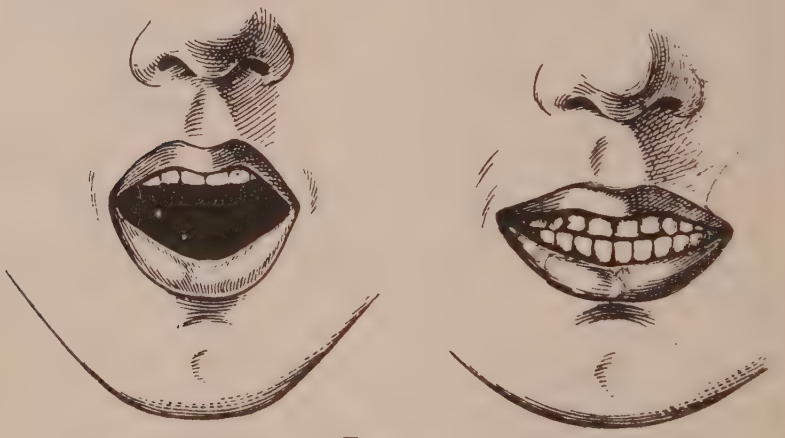


FIG. 21.

Normal emission of *ah*.

Emission of the sound *ah* while articulating *ē*.

is only necessary to be forewarned in order not to be entrapped by the first.

We have therefore had the idea of speaking while the patient's ears are deafened by the noise-machines; if he is deaf and lip-reads he should continue to understand; if he is deceiving us, he will no longer understand.

There is the objection that the noise-machines may worry the man to the extent of occupying the attention required for lip-reading, and we have modified the experiment by speaking in a very low voice,

the ears being carefully stopped up with cotton-wool moistened with glycerine, which is pressed on by the fingers of an assistant.

We proceed as follows: We begin by approaching our patient in a friendly manner, stating openly that he understands us perfectly. We stop up his ears and speak in a low voice; if he is silent, he is caught. The following is a pitfall to be avoided: any stranger who questions a deaf man will put one or several of the following questions: "Are you married? Where do you live? Have you any children? Which is your regiment? How were you wounded?" Without being very well up in lip-reading our man can guess the words "country, children," etc. We must show a little imagination and put simple but more unexpected questions.

Can it be proved in a more striking manner that the man hears and does not lip-read and that he is even able to understand the spoken voice when very slightly raised?

Extreme bilateral dulness of hearing.—What we have just said with regard to total deafness applies equally well to extreme deafness in which the injured man only perceives the loud voice on close contact with the ear.

The problem is a different one when the spoken voice is heard a short distance away. The watch is not heard, and we cannot check this. Tuning-forks are not perceived at all by air- or bone-conduction, which is very suspicious, or they are only heard slightly, unequally or paradoxically so that the results cannot be registered with any confidence when the patient exaggerates.

The test of the spoken voice with the eyes shut

furnishes quite conclusive information according as to whether the man is sincere and always answers when spoken to a short distance away, or is deceiving us and makes wild mistakes beyond all probability.

This test is not practicable if the voice ceases to be heard beyond a few centimetres. Hearing-tubes then come into use.

A man who hears at a short distance away will

FIG. 22.—The two tubes are held by an assistant without the from the tubes. The simulator believing he is being

hear through the hearing-tube; if he refuses to do so it will show his bad faith.

If he consents to it, we set the trap of speaking to him across a closed tube; the sonorous vibrations then pass through the air and the auditory meatus which is incompletely blocked up by the tip of the tube; we can thus estimate whether the voice is or is not heard at about 1 metre instead of at the few centimetres previously obtained.

We proceed differently but on the same principle. The patient has a tube in each ear. He turns his

back to us and closes his eyes ; without his knowledge an assistant, and not the observer, holds the tubes. The observer speaks while stepping back by degrees 1, 2, 3 or 4 metres, the deaf man still answering. He is caught in the very act. This method has often succeeded with us. We specially recommend it.

We check the lip-reading if the man concerned professes to understand by this means alone ; but

patient's knowledge. The observer speaks at some distance away spoken to through the tube, hears and repeats.

here we must be on our guard. We know, in fact, that the eyes furnish for the individual of good faith marked assistance when he is at such a limited distance away that he can understand with his ears certain syllables and vowels though not all the sounds which compose speech ; we must, therefore, not be in too great a hurry to conclude that the case is one of simulation.

The tests for the reflexes maintain their value ; the noise-machine test informs us as to the absence of an important lesion of the internal ears when normal

voice-raising is produced; simulation is plainly indicated when the patient who is really deaf in one ear pretends not to hear with the other, for the use of the noise-machine to the two ears separately gives clearly contrary results.

Total unilateral deafness.—Simulation of unilateral deafness is the easiest to detect. The means are not wanting. We have seen that the "false" Rinne of Lermoyez and Hautant constitutes a proof of sincerity. We must remember of what it consists; the patient, totally deaf in one ear, nevertheless perceives the sound of a vibrating tuning-fork on the mastoid of that side; this is only apparent, the sound being perceived not by the affected ear but by the good one.

The simulator, on the contrary, having decided to hear nothing with the would-be deaf ear, acknowledges no perception of sound.

Weber's modified test gives conclusive results in patients who have not been forewarned; we will recall it. The patient perceives the tuning-fork on the vertex in the good ear; if we close the meatus of that ear he says he no longer hears anything, an evident untruth, for the auditory sensation has not been suppressed but rather reinforced.

Stoppage of the meatus with the finger is not sufficient to prevent the spoken voice from being understood. We should strongly suspect the good faith of a man who ceased to repeat what was said to him when this simple means was employed. It is equally very suspicious if the high-pitched tuning-fork c^2 (ut^4) set vibrating in front of the ear said to be deaf, is not heard, for under these conditions it should be perceived with the opposite ear.

A great number of experiments are based on the following principle: we speak alternately and very quickly in one or other ear through a speaking-tube or telephone; the subject should repeat as soon as he hears; he has to pay great attention so as not to become careless and repeat once or twice what is said into the ear which he pretends is deaf; he would in such a case be indisputably convicted of fraud. This experiment rarely succeeds, for the patient soon becomes able to bring it to a deadlock by answering with prudent slowness; it deserves, however, that we should devote to it these few words of description borrowed from Halphen's thesis :—

Lucæ speaks alternately into two hearing trumpets connected to the two ears. The patient has his back turned. He will answer the question or hesitate. The hearing person cannot make a mistake.[1]

Kern has the same phrase pronounced by two different examiners through two speaking-tubes attached to the auricles. The one speaking to the affected ear leaves out something. If the patient repeats the phrase with the omission it shows that he has heard with the deaf ear.

Muller has two absolutely different phrases pronounced close to each other. The injured man who is deaf in one ear will only repeat the sentence spoken in front of the good ear. The simulator is embarrassed; he hesitates and makes mistakes. This test would seem to be conclusive only if the telephone is used so as to prevent the two phrases reaching the healthy ear.

[1] The tubes must be very long so that the observer can go far off, without which he will always be heard by the good ear even when he speaks into the tube leading to the ear said to be deaf. This cause of error gives rise to serious mistakes, and this test is a particularly poor one.

Stenger has invented an experiment established on quite a different principle. Let us suppose there is deafness of the left ear; we find at what distance a certain tuning-fork is heard by the right ear; we now set an identical tuning-fork vibrating immediately in front of the deaf ear. If we then bring the first tuning-fork to the good ear it will be still perceived at the distance first noted if the left ear is really deaf, and at the same distance from the right ear as the one vibrating in front of the left ear, if the left ear hears this tuning-fork.

What takes place?

(1) If the left ear is *deaf* it does not hear the tuning-fork on its side; its presence does not modify the perception of the right ear, which always hears its own tuning-fork at the same distance.

(2) If the left ear *hears* the noise of its tuning-fork, when it is brought closer it covers the sound of the right side tuning-fork which the patient no longer hears; the two tuning-forks are only heard together when their intensity, that is to say their distance, is the same on both sides.

Escat's *test with unisonant tuning-forks* is different, though based on the same principle:—"When the two ears of a normal person are submitted simultaneously and respectively to the influence of two sonorous sources of the same pitch and quality but of different intensity, the perception of the resulting unison is lateralised entirely in the ear submitted to the more intense of the two sources, whilst the ear submitted to the less intense sound seems to receive no impression" (Escat).

Escat uses two tuning-forks a^1 (la^3; 435 D.V.) of the same pitch and quality, but of different size and

consequently different intensity; one in fact weighs 305 grammes and vibrates for 180 seconds; the other lighter one, 37 grammes vibrating for 70 seconds.

The test properly so-called consists of three stages:—

First stage.—The small tuning-fork, vibrating feebly but sufficiently to be observed by a normal ear, is held in front of the left ear which is supposed to be deaf, two centimetres from the meatus; whether deaf or simulating the man under examination answers, "*I do not hear it.*"

Second stage.—Immediately this same tuning-fork is placed two centimetres from the right ear; whether deaf or simulating he answers, "*I hear it.*"

Third stage.—While the small tuning-fork is vibrating in front of the right ear, we bring the large tuning-fork, vibrating strongly, in front of the left ear.

On being asked which side he hears it the deaf man answers that he hears it on the right side, which explains perfectly that his left ear really hears nothing.

The simulator may give two answers: "I hear nothing," or, "I hear on the right side."

In the first case he is clearly simulating, for if his left ear is really deaf there is nothing to prevent his hearing the small tuning-fork with the right ear.

In the second case the test is indecisive; we must have recourse to the counter-test. For this it is sufficient, the large tuning-fork being kept in front of the left ear (supposed to be deaf), to withdraw the small tuning-fork from the right ear or to stop the vibrations with the fingers.

To the examiner's question, "Which side do you hear it?" the simulator nearly always answers, "I

hear it on the right side." The deceit is evident; hearing it all the time on the left side he did not perceive the suppression of the small tuning-fork on the right side.

These experiments with the tuning-fork are attractive from the scientific point of view. They are

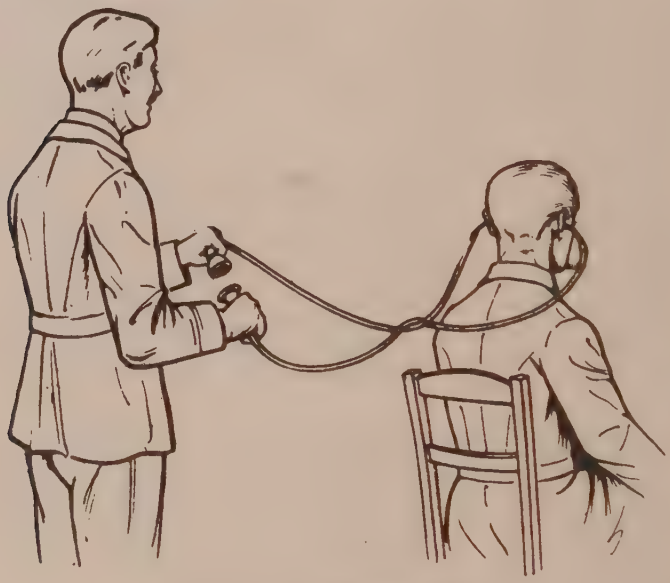


FIG. 23.—Bourgeois' test.

The subject acknowledges that he hears with the right ear. He simulates deafness of the left side. In the *first stage* the observer does not speak through any tube; the subject repeats what he hears.

probably of little practical value from the point of view of the medical report by reason of the extreme difficulty often experienced in interpreting the answers of the patients.

Without thinking either of Stenger or Escat, one of us (Bourgeois) formulated an analogous test much

more simple and demonstrative to the eyes of the layman.

This test of the hearing-tubes is based on the following principle (it was brought forward in a Discussion in Nov. 1915) :—

The injured man who simulates a unilateral deaf- declares his inability to hear the voice when it is spoken loudly into the ear which he pretends is deaf, while the circumstances of the experiment are such that he could not have failed to hear it with the good ear.

The experiment can be made in two ways :—

(1) Let us suppose that the injured man acknowledges good hearing in the right ear and extreme deafness in the left one. He is seated with his back turned towards the observer, the end of a hearing-tube being placed in each ear ; the two tubes are rolled one over the other, a very important precaution, so that he does not guess from the movements of the tube which ear is being spoken into.

Stopping up of the auditory meatus by the hearing tube is quite insufficient to hinder the perception of the voice, even when whispered, by the good ear. Therefore, we speak in the ordinary or whispered voice but not through the hearing-tubes, the mouths of which are directed downward ; we then utter a number of figures which the subject hears with his good ear and repeats immediately ; suddenly we bring the hearing-tube of the affected ear a few centimetres from the lips ; at that moment the man declares he hears nothing more ; he is silent. We may conclude from this test not only that the ear said to be deaf is not really so, but that it hears by the tube the whispered or the ordinary voice, whichever we use.

(2) We have made the test in another way: We begin by speaking in a low voice through the hearing-tube on the side of the ear said to be deaf; the subject does not hear it: we gradually raise the voice until the loud and even the shouted voice is reached; the patient still does not repeat what we

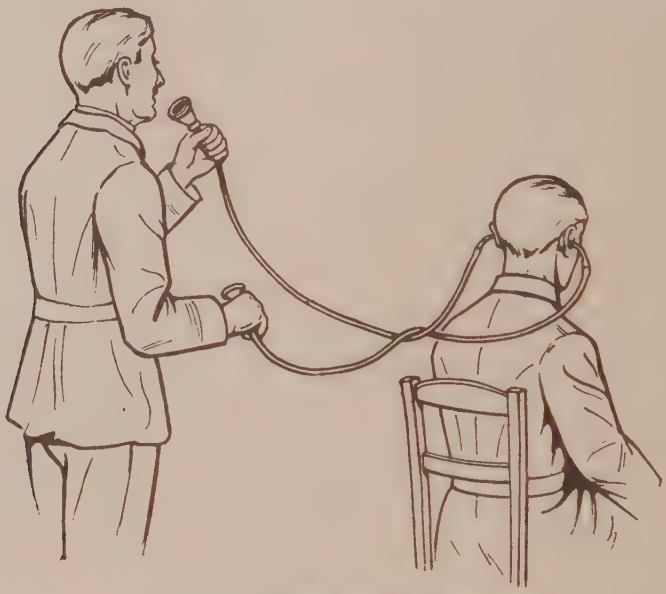


FIG. 24.—Bourgeois' Test.

Second Stage: the observer speaks in the tube on the left side; the subject is silent; however, he ought to hear it all the time, at any rate with the right ear.

say; nevertheless, he must have heard, if only with the good ear.

It is easy to explain the silence of a simulator by practising the experiment on ourselves; if we place ourselves under the conditions necessary for its performance we shall see that the sound seems only to arrive on the side on which the hearing-tube conducts it to

the ear ; the other ear to which the sound arrives simply by the air seems to receive no impression whatever, as though it were put completely out of the reckoning. A patient who is really deaf in the ear into which we speak through the hearing-tube, hearing nothing by this ear, continues to perceive the sound by the other and repeats as if we had not spoken through the tube. A normal and sincere person hears very loudly through the tube and repeats what he hears ; if normal, but a simulator, he finds himself suddenly only able to hear with the ear which he pretends is deaf ; he naturally thinks that this is the only ear being tested, and is silent.

We have made this experiment on sincere subjects and on undoubted exaggerators ; it has given us very convincing results. It is easy to carry out even for those who are not versed in Otology.

CHAPTER XIV

FUNCTIONAL EXAMINATION OF EQUILIBRIUM

Preliminary examination. — The consideration of the former histories of which we have spoken in a previous chapter, will have already given us information in regard to disturbances of equilibrium which may have shown themselves from the first moments of the accident. This history is of importance, for it is not very likely that marked disturbances will be present at the time of the examination for the medical report, when the injured man has not presented serious perturbations of equilibrium during the days following the injury. Experience has, in fact, taught us that vertiginous phenomena secondary to labyrinthine injury are generally of relatively great intensity at first, but that they decrease subsequently.

We should also take note of the man's appearance on the day of his arrival, how he habitually goes to and fro after his arrival in the hospital, so as to be able to compare his ordinary manner with the disturbances he may complain of during the examination.

The questioning bears not only on the past but on the present; it is very important to find out exactly the frequency, the intensity and the modality of the vertiginous attacks. Vertigo is a sensation

so painful, so agonising and so impressing even in abortive cases, that patients always find descriptive expressions exact and vivid enough to depict it in such a manner that we readily believe in their sincerity. The simulator, on the contrary, does not know how to explain exactly the sensations which precede the attack, its horrors, its frequency or its duration.

The examination properly so-called, as in the case of the hearing, deals with two orders of phenomena : some are to a certain extent voluntary, as walking and standing upright ; others are independent of the will, such as Barany's reflexes and Babinski's electric reactions.

Investigation of the equilibrium when standing upright and walking.—Equilibrial disturbances of labyrinthine origin obey Romberg's law, that is to say they are greatly increased by closing the eyes. Sight, it has been said, acts as a " crutch " to the sense of attitude. Thanks to it the patient can correct the erroneous impulses from his internal ear and the disturbance of equilibrium is diminished ; without sight he is indefensibly at the mercy of his labyrinth and he totters.

Standing upright.—For the purpose of investigating the equilibrium in the standing upright position, the man holds himself straight up, the feet near each other, and not with the heels together.

We ascertain whether there is normal equilibrium, tottering or a tendency to fall. The latter always takes place in the same direction, in general to the side of the affected labyrinth, or, in a bilateral lesion, to that of the most affected, but it varies according to the position of the head, that is to say of the labyrinth in relation to the body. Should there be a

lesion of the right labyrinth, the body remaining stationary we turn the head 90° towards the right; the tendency to fall is no longer to the right but backwards; in fact the injured labyrinth has become posterior in position. If we now displace the head towards the left the tendency is to fall forwards.

This variation of the tendency to fall according to the position of the head in relation to the trunk is of great importance, for it indicates that the lesion is labyrinthine and not cerebellar, in the latter case the direction of the falling being the same whatever the position of the head.

We then perform the same experiment, the patient standing on one leg; after this we begin all over again, the patient having his eyes shut.

Walking with the eyes open.—Walking with the eyes open may be normal in spite of a vestibular lesion. The more marked cases will show a slight lateral inclination, in still more pronounced cases the classic staggering called "duck's walk," reeling like a drunken man, with the legs apart; finally when of a still greater degree the patient falls after going a few steps, in the ordinary course of things always in the same direction.

Walking with the eyes shut. Babinski-Weil's test.—We have kept till the end *walking with the eyes shut* because it is the most delicate test, the one which detects the slightest equilibrial disturbances and which indicates most precisely the direction of the pathological impulse in the mild cases most often met with by the expert. Cestan's [1] communication has shown us the fundamental importance of this test when applied according to the Babinski-Weil method.

[1] *Soc. Méd. des Hôp.*, 1916.

The experiment is made in a room five or six yards in length and at least four wide, in which the subject can turn round without knocking against anything. He is placed with his eyes shut at one end of the room, exactly in the centre; he is ordered to walk across its whole length, advancing and retreating without opening the eyes and without stopping; the observer must prevent him from knocking against obstacles; we make him walk forwards and backwards thus ten times.

A normal subject will hardly deviate at all and certainly not always in the same direction; we do not count as pathological deviation the changes of direction due to an accidental irregularity in starting, to hesitation or a momentary false step.

The man whose labyrinth is affected, on the contrary, nearly always deviates in a very particular way. When he walks forwards he inclines constantly and almost regularly towards one side, say to the right; in the backward walk he inclines in the opposite direction, to the left in the present case, so much so that after a certain time he can be seen to walk in a line at right angles to the original direction and may even finish by going in an opposite direction to that in which he started off.

Not only is this test very delicate, but it can certainly never be simulated by a patient unacquainted with it, whilst staggering, tottering, balancing on one foot or on two are more under the control of all.

Cestan, Sauvage and Descomps have been desirous of making the test still more delicate by rendering the patient more sensitive by turning him round once with the eyes shut. We must, however, remember that this action is not without an effect; it excites the

labyrinth, tending to create an impulse towards a certain side; if the patient turns from left to right he is carried towards the right; consequently this

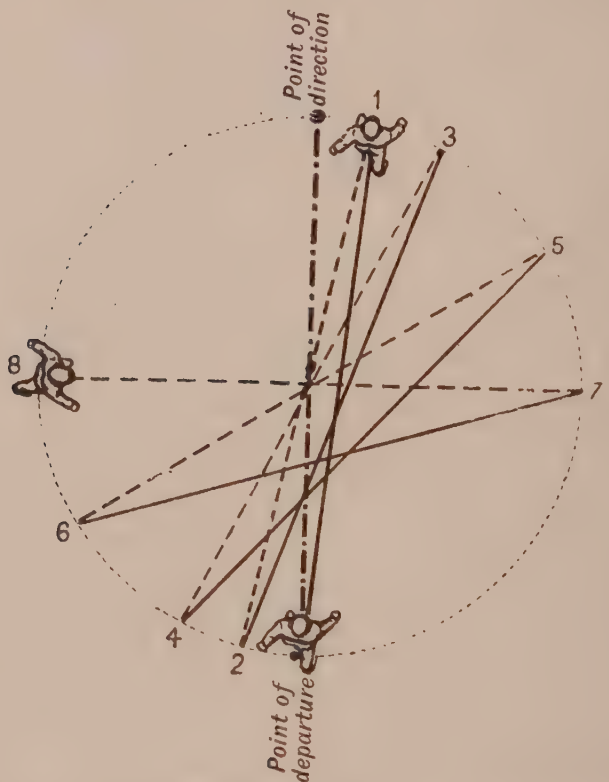


FIG. 25.—Babinski-Weil's test.

The subject deviates to the right in advancing, to the left in retreating. After going to and fro several times he follows a direction perpendicular to the initial one. The plain lines indicate the walking forward, the dotted ones the walking backward.

rotation towards the right will render him more sensitive to a spontaneous impulse to the right, but it might combat to a certain extent a spontaneous impulse to the left.

Consequently if we wish to make the experiment in this way, it must be practised twice, first after a turn to the right and then after a turn to the left.

Search for spontaneous nystagmus. — Spontaneous nystagmus usually accompanies an intense and relatively recent labyrinthine lesion; it indicates irritation of the vestibular nerve-endings and varies accordingly.

In the course of a vestibular lesion at its full height the nystagmus is easily disclosed during direct vision, the patient looking straight in front of him; but as the irritation of the nerve diminishes, on account of its cure or its destruction, the equilibrium of the eyeballs tends to become re-established; the nystagmus is then only perceptible during oblique vision, and soon even disappears.[1]

Associated with the other elements of the vestibular syndrome, namely equilibrial disturbances and vertigo, this symptom is of great importance; it is then of interest to note it carefully on the ob tion sheet, describing its characteristics, its direction to the right or left, its horizontal or rotary nature, its course. But it is of no interest to us when it occurs quite by itself; it then becomes an ordinary symptom of divers nervous or ocular affections (Hautant).

Induced nystagmus.—**Barany's tests.**—We shall now, by artificial excitation of each vestibule,

[1] Nystagmus consists of two distinct movements: one hardly perceptible draws the eyeball gently in one direction; this is the slow movement. The other, a quick reactionary movement in the opposite direction, constitutes the more easily visible rapid movement; in practice the latter direction designates that of the nystagmus. Further, according as the eyeballs are displaced following a horizontal line or in a vertico-frontal circle, the nystagmus is called "horizontal" or "rotary."

estimate its reaction, from lateral deviation of the trunk and limbs to the appearance of nystagmus and the complete labyrinthine syndrome, *i.e.* vertigo and vomiting ; as a matter of fact, we do not voluntarily go as far as to provoke these labyrinthine symptoms, for the expert should avoid all specially disagreeable manœuvres except those absolutely necessary, both in the interest of the medical report and in order to insure the good will of the subject.

Provoked nystagmus constitutes the fundamental symptom of Barany's tests [1] which are at the present time classical ; it presents the valuable advantage of being subject to a measurement which can be put down in figures ; it can be calculated by its duration in seconds, this duration being directly proportional to the excitability of the organ examined. We must not be misled with regard to the relative value of the figures obtained or give to the results of the experiment a precision contrary to reality ; it is important to consider the figures, but we must only take into consideration *great* differences between one subject and another ; the duration of so-called

[1] The physiological basis of Barany's tests is as follows : *all provoked movement* of the endolymph in a semi-circular canal excites the vestibular nerve endings, chiefly in the ampulla, and determines the production of nystagmus which presents the two following characteristics :—

1*st*. It is directed in the plane of the excited semi-circular canal, that is to say, excitation of the horizontal canal gives a horizontal nystagmus, excitation of the vertical canal a rotary nystagmus.

2*nd*. The slow movement of the nystagmus is in the same direction as the endolymph moving in the excited semi-circular canal. The quick movement, that which in practice characterises the nystagmus, is then *in the opposite direction to the endolymphatic current*. We must always have these two principles in mind in the course of our vestibular examination. (See *Précis de pathologie chirurgicale*, Vol. II. Bourgeois, *Troubles de la fonction d'equilibration*, p. 91.)

"normal" nystagmus for each test is only approximate, and only when it differs considerably must it be looked upon as pathological; it is not rare to find great differences in the figures on the report sheets of the same subject, put down by successive observers; the differences between the two ears of the same person are more significant, especially if they are reproduced regularly in two or three repetitions of the test. Whichever it is, this possibility of measuring provoked nystagmus is of so much advantage that making the test should not be long delayed.

We must, however, know how to do without it; it has seemed to us impossible to note movement of the eyeballs in intractable, timid or unintelligent subjects; they refuse to put their eyes in the required position; they blink; they stiffen themselves; they interrupt the flow of the water; briefly, it is better with such to be content to study the deviation in walking and the movements of the upper extremities. Galvanic electrisation according to Babinski is very painful if carried to the extent of producing nystagmus; we shall content ourselves with the deviation of the head and trunk.

1. *Rotation test.*—The man under examination is seated in a special armchair having a crank by which it can be turned round, or, more simple still, a swing the cords of which are wound round each other ten times.

He sits straight up, his head bent slightly forward. He has put on him a pair of spectacles, the ground glass of which prevents him from fixing his eyes which are open, on one particular point; in this way the movement of the eyeballs is uninfluenced.

If the right posterior labyrinth is the one to be

tested we set the chair rotating with a regular movement from the patient's *right to his left*; the speed is regulated so as to make ten turns in 20 seconds; the chair is then stopped suddenly.

Result in a normal person.—The subject looks straight in front of him into space, strong horizontal nystagmic movements *to the right* are seen; they gradually become less, the duration being from 25 to 30 seconds.

At the same time we shall notice that there is a tendency to fall *to the left* when in Romberg's position, and an inclination *to the left* when walking with the eyes shut.

If we ask him to lift up his two arms in front perpendicularly to the body, the eyes being shut, then deviation *towards the left* will be noted.

The subject is seated in front of us, the eyes open at first, then shut, and we ask him to touch alternately our knee and index finger which is raised to the level of our chest; he carries out the movement correctly whilst he can see and deviates to the left when he shuts his eyes.

Therefore, with nystagmus to the right there is deviation of the body and limbs to the left.

This contradiction explains itself, since the nystagmus to the right corresponds to the quick movement destined to correct the slow movement to the left; it is this slow contraction which is directly caused by the vestibular excitation, but as the nystagmus is named according to the quick movement we call it the opposite.

In reality the vestibular apparatus has been set in motion towards the left; on the sudden stopping the semi-circular canals have become stationary, the

endolymph has kept on moving and has caused an inclination of the eyeballs towards the left (slow contraction, the opposite to the nystagmus), as also of the walking with the eyes shut, the body in Romberg's position, the arms, the index finger.

To examine the left vestibule we turn him from left to right ; the results are exactly opposite.

Results in a pathological condition.—As with all reflexes Barany's can be exaggerated or diminished.

Exaggeration.—Exaggeration is shown by a longer period of duration of the nystagmus, but above all by exaggeration of the phenomena of deviation which may go as far as falling down suddenly and the occurrence of intense vertigo accompanied by pallor, cold sweating, nausea and even vomiting.

This exaggeration does not positively reveal a pathological condition ; certain people, otherwise quite healthy, have labyrinths more easily excited than those of others, and it does not denote disease if they are unable to waltz or turn on a " round-about."

A momentary state of nervousness or of irritable weakness may perhaps produce hyperexcitability of the labyrinth. In any case this happens sometimes in men who have been concussed ; we readily connect it with auditory hyperæsthesia which is so frequently present. Hyperexcitability when marked constitutes a presumptive symptom in favour of the reality of the concussion ; it indicates further a favourable prognosis. Any serious lesion of the vestibule causes hypoexcitability.

Diminution or abolition of the reflex.—Let us suppose in the first place that there is a bilateral lesion ; if *total* it involves *the absence of all reaction ;* there is no nystagmus or equilibrial disturbance, no

deviation on walking and in the movements after rotation ; if *partial*, diminution or absence of nystagmus may be noted, but the persistence of disturbances of equilibrium in walking and other movements.

FIG. 26.—Barany's rotation test (10 turns in 20 seconds). Post-rotation nystagmus in the opposite direction to the movement of rotation.

Let us suppose there is a lesion of the right vestibule, for example.

We commence by turning our subject from left to right, that is to say we excite his healthy labyrinth. We register almost normal results, though slightly lowered ; nystagmus to the left for 20″,

leaning to one side, deviation in walking and in movements of the limbs to the right.

We then wait a few minutes and recommence the test in the opposite direction, from right to left, in order to excite the right labyrinth which is supposed to have been destroyed. On finishing the ten turns we stop suddenly and we may note horizontal nystagmus directed towards the right ear; the nystagmus is feeble and lasts only a few seconds, but it is well marked. The inclination of the trunk, deviation of walking and movements to the left, but in a much less marked degree than after testing the left labyrinth, are to be found.[1]

[1] How is it to be explained that excitation of a destroyed vestibule may still give rise to reflex movements ?

It is because, in reality, rotation in one direction or another tests the two vestibules at the same time, though to an unequal degree.

Let us consider the diagram, Fig. 27, which represents the two

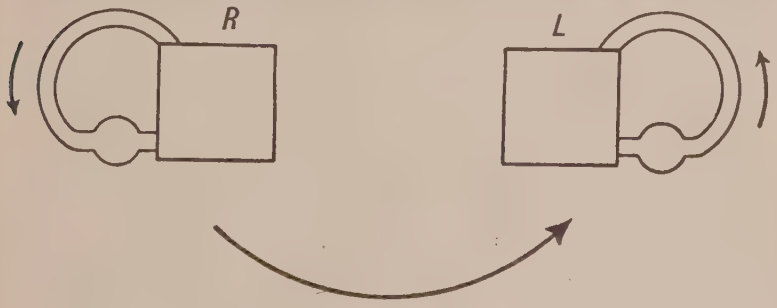


FIG. 27.

vestibules and the corresponding horizontal semi-circular canals of a normal subject; when we impart to the two a movement of rotation from right to left it produces, on stoppage, in the interior of the two canals, a movement of the endolymph in the direction of the arrow.

It is admitted that on the right side the fluid reaches the ampulla and attacks some excitable nerve-endings after having traversed the whole extent of the canal and with a speed greater than that on the left side where the ampulla received the fluid immediately after its exit from the vestibule. Whether this is the real reason or

Failing the swing or revolving chair this test may be practised by making the patient turn round on himself five times (Grivot) or round a stick as the centre (Moure).

Excitation thus produced does not always bring about nystagmus, but it acts sufficiently well on the equilibrium in the upright standing position and in walking to give a useful indication. Grivot has proposed an interesting chart for writing down the intensity of the deviation.[1]

Caloric test.—Barany has contrived a means of provoking nystagmus by the application of cold or heat to the middle ear, and through it to the semi-circular canals. He believes he can in this way give rise to a current in a vertical direction in the endolymph, the cooled particles sinking and the heated ones rising, as actually takes place in a thermo-siphon. In reality the facts do conform to the theory; the excited semi-circular canals are those which are in the vertical plane at the time of the experiment.

This test differs from the rotation one in the

not, the respective excitations of each labyrinth brought about by the same movement of rotation are of unequal intensity, the right being in this case the strongest, but the reflex movements which we note correspond to the sum of the two excitations.

If the duration of the nystagmus furnished by the excitation of the right vestibule is represented as 20″ and that furnished by the left labyrinth as 10″, the figures are reversed if the rotation is from left to right; in the two cases the sum of the two excitations gives a provoked nystagmus equal to 30″.

If our right vestibule is destroyed it becomes inexcitable and its contribution to the nystagmus = 0. Rotation from right to left gives 0 + 10″ = 10″.

Rotation from left to right gives 20″ + 0 = 20″.

Thus, what we must consider when arriving at the result is not so much the actual value of the duration of the reactional phenomena and in particular the nystagmus, as the difference between the results obtained by rotation in the two directions.

[1] *Paris médicale*, 1916.

manner in which the endolymph is set in motion; and apart from this the results are identical. But the two ears are here investigated separately, which is a great advantage; the same is not the case with rotation.

Instruments required.—(1) *Barany* used to employ some kind of douche, ground-glass spectacles for the subject's eyes (this latter may be omitted), a stop-watch and water at 27° C. (80·6° F.), which may be cooled down to 20° C. (68° F.) if the reflex is not very active. The principle consists in watching for the appearance of nystagmus and of measuring the duration of the incubation period in seconds.

FIG. 28.—Barany's caloric test with Brünings' apparatus.

Brünings prefers to measure the quantity of liquid necessary for producing the reflex, and this is more convenient.

His *oto-calorimeter* is composed of a bottle furnished with a thermometer and a tap; the water which runs from it is conducted to the tympanic membrane by an

indiarubber tube at the end of which is an aural cannula made for a double current; this cannula exactly fills the auditory meatus; at its outlet a second tube conducts the water to a graduated glass vessel situated below the level of the ear which is being tested. The bottle and graduated glass are placed

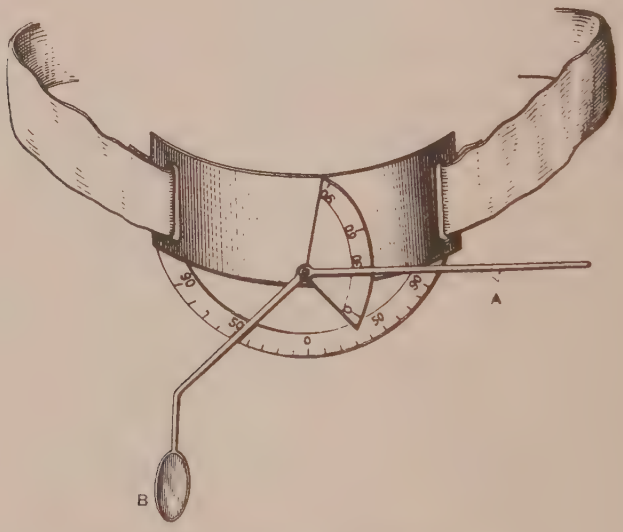


FIG. 29.—Brünings' Oto-goniometer.

A. Mobile indicating rod which must be placed on the figure 30 of the vertical dial. It indicates the direction of the horizontal canal.

B. Mirror, the rod of which should be on a level with the figure 50 on the horizontal dial.

on a board fixed to the wall. The water used is at 27° C. (80·6° F.), or at 20° C. (68° F.). Brünings has proposed, moreover, exciting the horizontal canal which is the most easily influenced by differences of temperature on account of its being external; it is sufficient to place the subject's head in such a position as to render the horizontal canal vertical

(bent back through an angle of sixty degrees); the oto-goniometer enables us to be sure that it is in such a position.

The *oto-goniometer* is a little metal plate having on its anterior surface 2 segments of a dial; a band of woven material going round the head maintains it on the forehead.

On the right side of the vertical dial, graduated from 0 to 90° is a movable rod; on the horizontal one there moves a rod ending in a little mirror on which the man under examination fixes his eyes during the test.

Objective examination beforehand.—An ear must not be irrigated before we are sure there is no obstacle in the meatus, cerumen or anything else, which would hinder the access of the water to the tympanic membrane. The extreme congestion which accompanies acute otitis is opposed to the production of caloric nystagmus; the absence of nystagmus in such a case has no significance. The presence of a large dry perforation of the tympanic membrane exposes the tympanic cavity to re-infection even when the operations are carried out according to the rules of asepsis; and if asepsis is possible with the douche syringe, it is not so with Brünings' apparatus. It is preferable in such a case to replace the water by cold air. Dundas Grant has invented a very practical instrument which will be described later on.

A large perforation with suppuration is not a contra-indication, but the water goes directly on to the labyrinthine wall of the tympanic cavity and the effect of the cold is much more pronounced; this must not be lost sight of when calculating the effects produced.

Barany's technique.—The subject is seated, the head in the upright position ; one ear is irrigated with the hydrostatic douche containing water at 27° C. (80·6° F.) ; the watch is set going and the appearance of nystagmus watched for either while the patient is looking through the ground-glass spectacles or fixing his eyes on the finger placed 25 cm. in the direction of the expected nystagmus ; the time necessary for the appearance of the nystagmus is noted ; we then continue to watch the nystagmus to note its duration.

Immediately after its appearance we make the patient walk with the eyes shut to see if he deviates in one direction or the other. If the reflex is only slightly active with water at 27° C. the experiment is repeated with water at 20° C. or even 15° C. (59° F.).

When the test is practised in this way, it is the fluid in the vertical canals which is set in motion ; on account of the position of the head, the nystagmus is rotary and directed to the side opposite to the irrigated ear.

Brünings' technique.—This is a quantitative method ; in order to be able to compare the results obtained for each ear and each individual, Brünings endeavours to operate under the most favorable conditions which are always identical. The horizontal semi-circular canal being the most external and the one most easily excited, he tests this one by putting the head in a certain " optimum " position and causing the patient to fix his eyes obliquely at a certain degree, favourable conditions for the production and measurement of the nystagmic reflex.

This " optimum " position is realised by two movements :—

(1) The head is inclined 60° backwards ; the

external semi-circular canal normally inclined 30° downwards, becomes vertical.

(2) The head being in the first position, we incline it 45° towards the *side which is being irrigated;* the horizontal semi-circular canal is then in the most favourable position; for a given quantity of water the reflex is twice as strong as when the head is in the first position.

The patient under examination is seated with the head upright; we begin by fixing on his forehead the oto-goniometer; we place the movable indicating rod on the vertical dial at the graduation 30°. When in this position it indicates the direction of the external semi-circular canal. With regard to the rod with the mirror at its end, it is pushed in the direction of the expected nystagmus to the division 50° on the horizontal dial.

The head is then bent backwards till the first rod becomes vertical; then 45° to the side to be irrigated; we order the patient to fix his eyes in the little mirror. We irrigate the ear while exercising on the auricle gentle traction upwards and outwards to straighten the auditory meatus; we watch for the appearance of nystagmus and at the first jerks stop the irrigation. We then read on the graduated glass the quantity of water which has passed into it; we order the man under examination to get up and note whether or not there is deviation on walking and of the movements.

Dundas Grant's technique.—It is reserved for cases in which there exists a dry perforation of the tympanic membrane. The apparatus consists of a tube of copper, coiled in a spiral and covered by an absorbent material. One of the ends fits into the ear under

examination; the other is connected to a thermo-cautery bellows.

Immediately before the test is started the jet from a flask of chloride of ethyl is directed on to the spiral apparatus for fifteen seconds; the coldness obtained by the evaporation lasts for seventy-five seconds. In normal cases provoked nystagmus appears after inflation for thirty seconds.

The hot-water test.—The heat-test is less employed

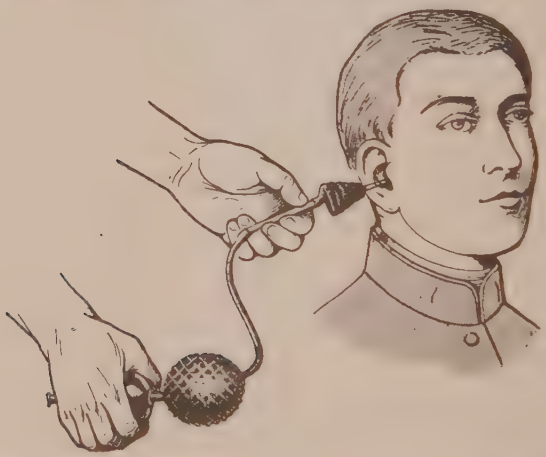


Fig. 30.—Dundas Grant's apparatus for the cold-air test.

than the cold, for it is less powerful; the water injected must not be above from 40° to 42° C. (104° to 107·6° F.).

The manner of using it is the same as that described for cold water; the results are opposite, that is to say the nystagmus is towards the irrigated ear and the deviation of movements to the opposite side.

We only advise its use in cases of spontaneous nystagmus towards the ear which is not being irrigated;

cold water would only exaggerate the symptom; warm water, on the contrary, will provoke an opposite nystagmus to the first, and this will render the action of the reflex more evident.

Results in cases with normal labyrinths.—With Barany's method and water at 27° C. nystagmus appears after 35 or 40 seconds of irrigation; it is rotary and directed to the side of the non-irrigated ear; it sometimes persists for a hundred seconds.

With Brünings' method nystagmus appears after the passage into the ear of from 70 to 75 cubic centimetres of water; it is horizontal. Here, as in the rotation test, deviation of the limbs or swaying of the body when in the upright position or when walking, is in the opposite direction to the nystagmus, that is to say towards the irrigated ear.

Results in a pathological condition.—(1) *Exaggeration.*—The nystagmus is seen to appear sooner than normal, after fifteen or twenty seconds of irrigation by Barany's method, and after the passage of from 40 to 50 cubic centimetres of water by Brünings'. If we continue up to the normal doses of excitation the duration of the nystagmus is prolonged and intense reactionary phenomena take place—vertigo, falling down and vomiting—so that we have to be careful about starting them; if they occur we can afford relief by placing the head in the upright position.

(2) *Diminution.*—Nystagmus fails to appear after normal excitation; we must prolong irrigation to one minute and sometimes to 300 cubic centimetres of water. Labyrinthine excitability is inversely proportional to the duration of the irrigation or the quantity of water used.

If after this amount of time or water we cannot induce nystagmus, we must stop the irrigation and see if there is deviation of the trunk or limbs.

In cases of complete inability to produce nystagmus the reflex is abolished, the labyrinth is inexcitable.

(3) *Inversion.*—In certain very exceptional cases and in which symptoms of disturbance of equilibrium are marked, there is an inversion of the direction of the nystagmus and of the swaying; the nystagmus occurs in the direction of the ear being irrigated with the cold water.

Babinski's electrical test.—The following is the principle of Babinski's test: the poles of the circuit of a continuous current being applied in front of each ear in a normal subject, there is to be seen an inclination of the head and the trunk towards the positive pole when the current attains to a sufficient intensity. This inclination is due to excitation of the vestibular nerves, and the results of the test are different in the case of labyrinthine lesions.

Armamentarium.—The armamentarium is simple—a battery of 24 cells grouped for tension with a rheostat, so that the intensity of the current may be increased or diminished; a milliampère-meter for measuring; two flexibles; two ordinary electrodes covered with chamois leather, about the size of a shilling-piece, which are moistened with salt water at the time of the experiment.

Method of procedure.—The patient stands up, the feet together, the eyes shut; the observer standing in front of him applies the electrodes one in front of each tragus. The assistant increases the current very gradually, while reading the milliampère-meter; he stops when the observer gives the order after having

noted the inclination; he then gradually decreases the current down to zero.

Babinski has rendered the test more delicate by investigating the effect of electrisation while the patient

FIG. 31.—Electro-diagnosis according to Babinski. The subject inclines normally to the positive pole.

is walking with the eyes shut instead of standing upright; it is only necessary to have long enough flexibles suspended from the ceiling. Deviation in walking denotes lateral inclination with a very feeble current. This modification is not indispensable; there is perhaps no real advantage in refining these

tests to an extreme degree, for only very decided differences distinguish the pathological condition from the normal.

Result in a case with normal labyrinths.—The patient inclines the head, then the trunk to the side of the positive pole when the intensity of the current reaches about 6 milliampères; anything between 4 and 8 may be considered as normal. The impression produced is that of a feeble vertigo with a lateral impulse towards the positive pole, a tendency which it is impossible to resist. A stronger current produces nystagmus, but the test then becomes very painful.

Results in cases with diseased labyrinths.—The results of the experiment may be altered either by a diminution of the necessary electric intensity or, on the contrary, an increase, or, finally, a change in the direction of falling.

Lowering of the number of milliampères necessary to produce swaying implies labyrinthine hyperexcitability. A current of one or two milliampères may be sufficient in such a case. We may even see, in spite of the feeble intensity, a more violent impulse and marked vertiginous sensations, lasting sometimes a few minutes, whereas in normal subjects the vertigo ceases instantly. This hyperexcitability may exist alone or coincide with an anomaly in the direction of the falling.

Hypoexcitability or inexcitability is manifested by the necessity of raising the current to a notable extent above the normal amount or by the impossibility of producing the slightest vertigo by a current of 15 milliampères.

This study of the anomalies of the direction of falling has seemed to us extremely interesting.

Babinski has laid down from the beginning that in the normal condition the subject inclines towards the positive pole and that with a pathological condition he falls towards the affected ear or towards the one most affected, whatever be the direction of the current. Later on he recognised that his formula was applicable to the majority but not to all pathological cases.

Our experience entirely confirms Babinski's published views; it seems to us that the direction of the falling in pathological cases may be explained and we shall formulate Babinski's law in the following way: In the normal state the subject inclines to the side of the positive pole; in the pathological state he falls to the side to which he has a tendency to incline spontaneously.

Thus, in a case with a unilateral labyrinthine lesion we shall see that the patient when walking with his eyes shut is inclined nearly always towards the affected side; this would explain how the galvanic inclination obeys Babinski's law and takes place almost constantly in the direction of the affected or the more affected ear. But our observations also show that the passage of the current nearly always produces a falling *backwards* when an investigation of walking and standing previous to the eyes being shut, revealed that the patient staggered while walking without inclining more to the right than to the left, and tended to fall *backwards* when in Romberg's position.

Does not this analysis explain singularly the physiological mechanism of Babinski's test? In the normal condition the passage of the current produces an inclination towards the positive pole.

In the pathological condition electrisation exaggerates spontaneous inclination caused by the abnormal excitability of an affected labyrinth. If the labyrinth is destroyed there is no reaction.

Semeiological value of the test.—Babinski published his researches in electrisation of the labyrinth long before Barany taught us the utilisation of provoked nystagmus. However, the two tests have not by any means had the same success among otologists. A serious theoretical objection has been raised against the value of Babinski's sign; as far as experience goes we believe that observers have been content with experiments carried out without confidence and in too small a number of cases.

Theoretically the objection has been that the electrisation does not specially excite the labyrinth but the trunk of the nerve and even the brain, and that by reason of the impossibility of making allowance for each of these any conclusion was doubtful.

However, it can be proved that we have here a peripheral excitation and not a central one. What are, in fact, the combination and the order of the observed phenomena? The vertigo does not stand alone.

According to the intensity of the current there is observed, over and above the pricking sensation transmitted by the nerves of general sensation :—

(1) A very decided salt taste;
(2) Lateral swaying with slight vertigo;
(3) Nystagmus with more marked vertigo;
(4) Finally, the passage of the current may produce a sensation of sound.

Thus it is not the nerve centres in general or any

particular forms of special sensibility that are excited, but precisely the three branches which traverse the petrous bone, namely, the corda tympani, the vestibular nerve and the cochlear nerve.

This peripheral excitation of a sensory nerve-branch expresses itself by a movement; is not this the definition of a reflex? Babinski's diagnosis by electricity makes use of a reflex which has all the objective value of reflexes, which can be measured in figures by the milliampère-meter, and which is the most convenient for use and the easiest to tolerate. It is impossible, in fact, to formulate an objection to its practice; the test takes little time and is not at all painful.

Does this mean that it should be used in preference to provoked nystagmus? By no means.

Rotation should still be used, for it represents the physiological excitation of the semi-circular canals, and the caloric test remains valuable as allowing of investigation of each ear separately and even, indeed, of each group of canals.

But the "Babinski" is so convenient and so clear that we should like it always to be the one to begin with in order to know in a few minutes whether the vestibular system works normally or not; in the same way Lombard's hearing-test tells us, before any other test is used, whether there is or is not serious organic labyrinthine deafness, either unilateral or bilateral.

We will show the great value of the "Babinski" by a résumé of a series of twelve cases which represent the entire experience of one of us during the last three weeks in which he directed his otological clinic.

Twelve patients were submitted to vestibular

electrisation from October 1 to October 20, 1916. Four were considered from all other points of view to have normal labyrinths; they inclined towards the positive pole with the use of an intensity of 6, 5, 4 and 6, 7 and 9 milliampères; as for the last one there was very slight chronic catarrhal median otitis; there was nothing to explain clinically the slight increase of resistance to the continuous current.

One injured man remained completely unaffected by 18 milliampères; he had a wound of the head from a projectile which had caused total unilateral labyrinthine deafness.

Four men suffering from concussion from explosion of a shell were hyperexcitable, and all presented disturbances in walking and standing upright after closing the eyes. In three of them the deviation did not take place in the direction of the positive pole but in that of the spontaneous tendency to fall; the same inclination was remarked in a fourth patient with Menière's disease (paroxysmal vertigo), who deviated to the right on walking, showing no nystagmus or any other vertiginous disturbance after the passage of 300 cubic centimetres of water at 25° C. (77° F.) into his right ear, and in whom 4 milliampères caused swaying to the right whatever the direction of the current.

Do not the examples furnished by these twelve non-selcted patients corroborate our conclusions? We find three normal reactions in four subjects who did not show any vestibular disturbance, there only being a certain amount of hypoexcitability in the fourth; one case of complete inexcitability in an injured man whose labyrinth was destroyed; four cases of hyperexcitability in men suffering from

concussion and presenting marked disturbances of equilibrium, three of which inclined during the Babinski test in the direction of their spontaneous deviation; the same parallelism occurring in the case of Menière's disease.

CHAPTER XV

RESULTS OF EXAMINATION AND PREPARATION OF THE REPORT

When he has finished his long, detailed and often difficult examination, the expert is in a position to deal with the different data of the problem submitted to him, to know the nature of the lesion, its cause, extent, prognosis and the medico-legal consequences of the disability resulting from it.

An accurate anatomical diagnosis is indispensable ; we must know whether we have before us a case of organic or functional deafness, of external, median, internal otitis or mixed lesions.

It will then be necessary to establish the relationship between the ascertained anatomical condition and the injury alleged as the cause. Traumatic lesions of other parts of the body do not, as a rule, call for discussion as to their origin ; the question of etiology presents for the aurist, on the contrary, the greatest difficulties, for those injured in war, as by accidents in time of peace, are apt to attribute an old-standing deafness to a recent traumatism, and we often have great difficulty in determining how far their statements are in accordance with the real facts.

The third object of the medical report consists in putting together the tests for measuring the degree

of deafness and determining the intensity of the vertiginous disturbances. This last estimation is necessarily vague ; the measurement of the hearing can be fairly accurate ; the special psychological conditions at the time of the medical examination for report (so different from this point of view to a clinical observation) oblige us to be reserved, and we content ourselves with an approximation ; it is hardly possible for the aurist to write down that the acuteness of hearing is reduced to a third part or a quarter, as the oculist can do in regard to acuteness of vision ; we prefer to state that the subject is totally or almost totally deaf, or has extreme, medium or slight dulness of hearing ; we would willingly accept our colleague Molinié's proposition, namely, that aurists should agree to assign approximately the limits to similar degrees of deafness according to the auditory faculty for the human voice.[1]

We are not obliged to give to the prognosis a precision which may lead to difficulties ; we may consider as in all probability ameliorable all deafness accompanied by normal reflexes, and as having a reserved prognosis those cases where these same reflexes are abolished. Disturbances of equilibrium generally disappear at the end of a variable time.

The medico-legal consequences depend on the actual functional incapacity ; they are established according to the regulation instructions relating to categorisation and to discharge. We must report with the greatest accuracy all organic changes ; it is better to demand that the patient be kept under

[1] We might take as a basis Schwartz's classification, established according to the distance at which the conversational voice is perceived : below 1 metre ; between 1 and 5 metres ; between 5 and 10 metres ; between 10 and 20 metres.

observation and submitted to the check of an expert examination in a neurological centre in the case of all purely functional disturbances which have resisted our treatment.

PREPARATION OF THE REPORT

The form for registering the measurement of the hearing-power drawn up by the Minister of War, to be filled up according to requirements, is sufficient for simple cases which do not call for discussion ; it will always comprise a concise description of the normal or pathological anatomical condition, a diagnosis and precise conclusions.

A detailed report accompanies this form in all recommendations for discharge and in all those cases where there is a contradiction between the results of the examination and the statements of the injured man.

We propose to draw up this report according to the following plan :—

(1) **Former histories.** — To distinguish accurately between the narrative of the individual and the information furnished by his papers ; to set one against the other should there be need for so doing.

(2) **Actual condition.**—A. SYMPTOMS OF WHICH THE INJURED MAN COMPLAINS.—To omit none of his statements ; if necessary to transcribe them word for word.

B. OBJECTIVE EXAMINATION.—Normal or pathological condition. Lesions whether apparently of old standing or recent, spontaneous or traumatic.

C. FUNCTIONAL EXAMINATION.—(*a*) *Hearing.*— To refer to the acoumetric form ; but to state

the reason for reserve with regard to apparent results, if called for, and then to narrate in all their details the different tests of good faith; this clear detailed statement should be written out in such a manner as to be comprehensible by non-specialist examiners.

(*b*) ***Equilibrium.***—Reference to the case paper and report as to the genuineness and extent of the symptoms of which the patient complains.

(3) **Conclusions.**—*Total deafness, extreme deafness,* etc., with or without equilibrial disturbances.

Caused or aggravated by : anatomical and accurate etiological diagnosis. If it is a wound, mention the wounding agent.

Susceptibility or not to relief or cure.

Actual functional incapacity valued at . . .

Recommendation. — Combatant or Auxiliary Service.

Discharge No. 1, with or without pension or gratuity.

Discharge No. 2.

Transference to another department for further examination.

N.B.—These conclusions are of two kinds: the first are entirely medical; they relate to the existence and degree of the pathological disturbance, its causes and prognosis; the second are medico-legal and refer to the consequences of the disability as to functional incapacity produced, to military fitness and to discharge.

The specialist confines himself strictly to the conclusions of the first group when he is acting simply as a doctor treating the patient, that is to say, when he fills in the medical history sheet and the clinical

notes which accompany the patient from hospital to hospital.

He should only mention the functional incapacity or express a recommendation with regard to discharge when he is asked to give his opinion on the subject. Any estimate and recommendation should never be known by the man interested; they should be sent under sealed cover to the Committee on Medical Reports, for it is important that the medical examiner for the report, who is alone qualified to arrive at a decision, should be quite unprejudiced in doing so.[1]

The circular (309 Ci/7) of November 5, 1916, states among other things: "The rôle of the physicians treating the cases, and notably of the specialists, in making up the papers consists in furnishing the most complete anatomical and clinical information, so as to permit the only legal authorities, namely the examiners and the discharging Boards, to give any opinion or to make any decision on the legal effects arising from the disabilities.

"The doctors treating the case must, therefore, abstain from all personal estimate of the amount of invalidity and from any suggestion as to the precise decision to be arrived at by the Invaliding Board, apart from the exceptional cases where the Boards or the examiners ask for their advice in consultation. This advice ought to be furnished under sealed cover and without the patient knowing the tenor of its contents. . . ."

This decision seemed too rigid for practical purposes, the medical reporters being unprepared to decide for themselves as to the different degrees of

[1] Duco and Blum, *Guide du médecin dans les expertises médico-légales militaires* (Collection Horizon), p. 144.

invalidity in special affections, and a new circular (No. 413 Ci/7) of January 31, 1917, authorises the physician treating the soldier (1) to send *under sealed cover* to the principal medical officer of the discharge centre his personal estimate of the degree of invalidity and his suggestion as to the decision to be taken; or (2) to accompany the wounded man before the Board.

CHAPTER XVI

LESIONS OF THE EAR AND MILITARY FITNESS

The circular of April 1, 1916, has modified the old ordinances concerning the fitness for military service of the subjects of aural lesions.

External ear.— " Congenital or acquired atresia of one or both external auditory meatuses or malformations of the auricle should not be taken into consideration unless they cause deterioration of the auditory acuteness.

" Acute or chronic inflammations of the external ear (auricle, meatus) are never a reason for exemption ; they are compatible with combatant service."

Middle ear.—" Chronic otorrhœa with suppuration and a destructive lesion of the walls and contents of the tympanic cavity or of its adjacent cavities (osteitis, cholesteatoma) calls for postponement of service or temporary discharge.

" Subjects with these lesions will not be exempted or definitely discharged until all the means of treatment have been exhausted, including curetting the tympanic cavity or even performance of the petromastoid operation.

" Cicatrised perforations, without osteitis or

Application of the Circular No. 153 *CI*/7 *of July* 15, 1916.

OTO-RHINO-LARYNGOLOGICAL CENTRE OF THE REGION

OTO-RHINO-LARYNGOLOGICAL FORM

of the man named (Name, Christian names, age) _____

(rank and regiment) _____

Treated in the ____ *centre of* _____ *from* _____ *to* _____

Diagnosis on discharge: _____

DESCRIPTION OF THE OTOLOGICAL LESIONS

L. T. R. T.

Examination of nose: _____

Examination of naso-pharynx: _____

Examination of larynx: _____

Precautions to be taken (if called for) _____

Fitness for service _____

Principal of the Centre.

_____ the _____ 19____

cholesteatoma, with intermittent mucoid or muco-purulent discharge, are compatible with combatant service. They only call for classification in the auxiliary service when the auditory acuteness is below the limits fixed for combatant service."

[The purpose of the legislator is thus quite clear; he has distinguished between two kinds of otorrhœa; the first group includes cases of osteitis and cholesteatoma; we would add perforations of Shrapnell's membrane; these are cases of otitis liable to complications; they are dangerous to life; they must be dealt with surgically if we wish to cure them quickly and sufficiently to be of use; in the contrary case they must be rigorously cleared out of the Army. The second group comprises the immense legion of ear discharges with large perforations without osteitis or retention, and more or less profuse according to the hygienic care bestowed upon them. The patients would be discharged in time of peace; they should not, however, be prevented from taking part in the campaign; above all, they should not encumber our hospitals and pass the greater part of their time in them; the aurist should not expect ideal absolute drying-up of the discharge; he should content himself with curetting a blocked-up naso-pharynx, removing polypi and cleansing a profuse ear discharge, and then send the patient to his regiment with the statement: *fit for combatant service.* The oto-rhino-laryngological form figured above should be inserted in the soldier's documents for the information of the regimental doctor.]

"Sub-acute or chronic catarrhal otitis with intermittent deafness (tubal catarrh) is compatible with combatant service.

" Cicatricial otitis secondary to suppurative otitis or to unilateral or bilateral surgical operation is compatible with combatant service or auxiliary service according to the degree of hearing-power, which alone should be taken into consideration."

Internal ear.—" The same rules apply to suppurative lesions of the internal ear as given for suppuration of the middle ear. Unilateral or bilateral non-suppurative affections of the internal ear shown chiefly by subjective symptoms (vertigo, tinnitus, deafness) must not be considered in connection with the proposals concerned except as regards the resulting deafness and the lesions of the vestibular apparatus and nervous system which can be clinically detected."

Acuteness of hearing and deafness. Labyrinthine disturbances.—" The required amounts of auditory acuteness are as follows :—

" (*a*) *Combatant Service.*—The whispered voice with residual air must be heard at 50 centimetres.

" Loud voice between 4 and 5 metres.

" The word of command at 10 metres.

" (*b*) *Auxiliary Service.*—A quarter of the auditory acuteness required for combatant service, say, whispered voice about 12 centimetres ; loud voice, 1 metre 25 ; word of command, 2 metres 50.

" (*c*) Auditory acuteness below this calls for exemption or discharge."

[N.B.—Deafness for the whispered voice is difficult to check. Suspected individuals should be classified according to the hearing for loud voice alone (the authors.)]

" The deafness may come on alone or accompanied by tinnitus and vertigo.

" When the deafness is accompanied by tinnitus

and vertigo the latter symptoms should only be taken into account when they can be confirmed by neurological examination of the labyrinthine apparatus."

[Vestibular examination, Romberg's, Babinski-Weil's and Barany's tests ; test for voltaic vertigo.]

" (*a*) Total bilateral deafness calls for exemption or discharge.

" (*b*) Total unilateral deafness calls for classification in the auxiliary service, even when the auditory acuteness of the other ear is normal.

" (*c*) Partial unilateral deafness is compatible with combatant service.

" (*d*) Partial bilateral deafness permits of classification in the combatant service or in the auxiliary service according to the degree of acuteness of hearing ascertained."

FITNESS FOR AVIATION

(*Circular of April 1, 1916.*)

" Normal auditory acuteness with soundness of the middle and internal ears and especially of the equilibrial apparatus."

[There is no need to insist on the necessity of eliminating all men with affections of the tubo-tympanic apparatus, tubal catarrh, or atrophy of the tympanic membrane, in view of the enormous variations of barometrical pressure to which aviators are submitted.

The tests with the watch, loud and whispered voice will suffice for recognising a normal auditory acuteness.

Romberg's and Babinski-Weil's tests do not require special instruments. In the absence of a

chair or a swing, vertigo, or rather post-rotatory deviation, can be investigated by making the patient turn round on himself. An ear-syringe and water at 27° C. (80·6° F.) are sufficient to provoke caloric nystagmus, but these two last tests do not appear to us to be indispensable if all the preceding investigations have shown the ears to be normal, while if they had been shown to be otherwise, a negative conclusion would have been already arrived at.]

CHAPTER XVII

DISCHARGE No. 1.

Pensions. — ***Gratuities.*** — Retiring pensions for wounds and injuries arising from military service are due when these wounds and injuries are *incurable*, and from the point of view of their severity, they come under one or other of the six categories established by the law of 1831.

This last condition applies only to non-commissioned officers and men ; for officers it is enough that the infirmity renders them unable to remain on the active list and deprives them of the possibility of remaining thereon in the future.

The law of 1831 classified deafness under two categories :—

(1) Complete deafness of both sides resulting from injury or disease contracted during service is put down as No. 19 of the 5th class. It gives a right to a pension of 600 francs for a soldier of the second class.

(2) Very marked diminution of hearing on both sides, or complete deafness of one side with facial paralysis or destruction of the external auditory apparatus, resulting from injury or disease contracted during service comes under No. 50 of the 6th class.

It gives the right to a pension of 600 francs for a soldier of the second class.

The law of 1831 is in force so far as it has not been repealed, consequently the expert who finds himself confronted by an *incurable* disability coming under one of the classes enumerated by that law is obliged to adjudge the retiring pension in accordance with it.

Does this mean that we must adjudicate in the same way for all cases of bilateral deafness and unilateral deafness with facial paralysis? Not at all. To act thus would be to settle the future very imprudently, for a retiring pension is always awarded permanently.

The pension is reserved for *incurable* cases, and experience has taught us how careful we must be in giving a prognosis of incurability in a case of deafness or facial paralysis.

The question of incurability must in most cases be set aside and the injured man recommended not for a pension but for a gratuity which may be renewed or modified. The scale of these gratuities, much more elastic than that of the law of 1831, allows consideration of a much larger number of cases and more equitable compensation to the injured men.

Disabilities give no right to a gratuity when the disablement is valued at less than 10 per cent. It is worth while, however, to make note of an incapacity even of only 5, 7, or 8 per cent., because the amount of damage incurred is thus recognised and the rights of the injured man to future compensation in case of aggravation of the condition are maintained.

The indications given below have been furnished

to the expert examiners for the forming of their conclusions. They are not by any means of an authoritative character and are sufficiently elastic to permit of estimating each case taken individually. (*Circular of March* 24, 1915.)

"**Ears.—Loss of cartilage.**—The cartilage not being necessary for hearing, its loss presents chiefly an æsthetic inconvenience, detriment from which, as already seen, is not admitted by the law of 1898.

"The Vienna scheme admits, however 8 per cent.
Röpke .. .. 10 to 15 ,,

"The ear, like the eye, being capable of compensating for the opposite one, unilateral lesions must be carefully distinguished from bilateral ones. It is expedient also to separate dulness of hearing from deafness.

A. *Unilateral Lesions.*

Dulness of hearing on one side	10 per cent.
Deafness of one ear without noises or vertigo	10 to 15 ,,
Deafness of one ear with noises and vertigo	30 ,,

"*Aural suppuration.*—This is a question of disease (osseous caries) subject to serious complications, and not merely a disability; it calls for treatment; the hearing is nearly always involved, sometimes irremediably; the incapacity resulting from it is variable and may fluctuate between 20 and 50 per cent.

B. *Bilateral Lesions.*

Dulness of both ears	10 to 15 per cent.
Dulness of one ear and deafness of the other	25 to 30 ,,
Bilateral deafness	50 ,,

" *Vertigo.*—Vertigo is as difficult to prove as persistent pain; it is, however, a source of great inconvenience when it really exists.

" President Duchauffour, in doubtful cases, estimates an incapacity of	0 to 30 per cent.
" And in certain well-proved cases an incapacity of	50 to 60 ,,

These are average figures established according to the law dealing with workmen's accidents; they may also serve as indications for the application of the law of 1898; but the examiner for the medical report must remember that military law does not recognise the injured man's occupation, whereas the civil law, on the contrary, has for its object the reparation of the loss incurred and takes the man's occupation into account; the figures above mentioned will, therefore, err on the side of excess or insufficiency, according to the case, if judged by the standard adopted in civil practice.

Apart from this question of compensation, the medico-legal examinations for reports, whether military or civil, are quite similar; we have described the various considerations as completely as we have been able, hoping that our labour will serve not only for the present moment but also for the day when we shall all again have taken up our ordinary course of work.

INDEX

Abdominal cavity, projectiles in, 346.
Abscesses, associated with projectiles, 353.
in bone, reopening of, 705.
Absorption of rays, dangers of, in extraction of projectiles with aid of intermittent control of screen, 318.
Air regulator, 17.
Allaire radioscopic marker, 190.
Alternating electro-magnets, 361.
Aluminum cassettes, 40.
Aluminum filter in X-ray proceedings, 96.
Ambrine, application of, 778.
composition of, 777.
nature of, 777.
substitute for, formula for, 783.
Ambrine spray, 778.
American chuck, 502.
Americans and stereoscopy, 235, 237.
Ampérage, definition of, 8.
in production of X-rays, 9, 10.
Amputation, circular method of, in case of thigh, 389.
as last resort, 389.
above condyles, 392.
through deltoid muscle, 523.
dilemmas in choice of, 389.
of extremity with gas gangrene, indications for, 767.
of foot, partial, of Chopart and Lisfranc, 461.
of fore part, 463.
through infected parts, 390.
length of stump in, 383, 600.
position of scar in, 382.
prosthetic apparatus for, parts composing, 381.
Amputation neuromata, causes of, 601.
effects of, 602.
Amputation neuromata, site of, 601.
Amputation stumps, bony changes in, 580.
chronic ulceration of, 634–635.
length of, 383, 600.
neuromata of, 601–602.
obliteration of cavities in, 597–598.
re-amputations of, 596–597.
requiring further treatment, 582.
infection, moderate, 582.
severe, 584.
necrosis and caries, 586.
operations necessary to bring about final healing in preparation for artificial limb, 595.
osteosclerosis, 587.
radiographic appearance of, 589.
sub-periosteal bone, excessive, 588.
suppurating, 594.
ulcerations, 585.
satisfactory, 599.
shortness of soft parts in, 599–601.
Anæsthesia, 356.
Anatomical localisation. *See* Localisation, anatomical.
Andrault and Barret process of triangulation, 205.
Angle at which foot is set, 414, 429.
Angulation of fragments, 542.
Ankle, movable, with flexed knee, 430.
Ankle and knee joints, combined mechanism for, 435.
Ankylosis, definition of, 708.
due to defects of bony union, 547.
extra-articular, in articular end of bone, 709.
of peri-articular soft parts, 710.

Ankylosis, intra-articular, cause of, 708.
pathological conditions in joint due to, 708.
malpositions of, 717.
maxillary, due to auriculo-mastoid wounds, treatment of, 880.
pathological bases of, 709 *et seq.*
positions of election in, 717, 718.
prophylaxis of, 716, 724.
temporo-maxillary, due to wounds of auriculo-mastoid region, 872.
treatment of, 725, 738.
curative, 724.
accessory means of, 737.
correction by a succession of plasters, 735.
forcible correction, 733.
preliminary operations, 736.
preventive, 716.
with sinuses leading to epiphyses, operation for, 698.
varieties of, 708, 709.
extra-articular, 709.
intra-articular, 708.
Anode, 1.
Anticathode, 4.
cooling of, by water reservoir or current of air, 8.
distance from, to screen, 186.
double, 226 *et seq.*
Anticathode tube, 248.
Antitoxin treatment of gas gangrene, 768.
Appliances, with mobile joint, 123.
with universal joint, 126.
for use instead of hand. *See* Hand, appliances for use in place of.
Arm, artificial, articulation at elbow, 519.
attachment and arm socket, 509.
disadvantages of complete liberty of action, 521.
materials for, 512.
movements transmitted by stump to arm socket, 519.
ploughman's, 521.
position of steels, 513.
ratchet to fix elbow joint in flexed position, 513.
socket, 518.
types of, 509.
worker's, 518.
projectiles in, 269, 351.
Armlet, concavity of, 470.
Artificial limbs, active and passive, 381.
for amputation through arm, attachment and arm socket, 509.
types of, 509.
for amputation through forearm, artificial hand and appliances, 476.
attachment of, to elbow, 465.
attachment of, to shoulder, 467.
concavity of armlet, 470.
constituent parts, 464.
elbow joint, 470.
points of attachment, 465.
resistance to rotation, 469.
resistance to upward pressure, 469.
suspension of, 465.
for amputation through leg, with free knee joint, appliances with bearing upon tuberosities of tibia, 447.
appliances with end bearing only, 457.
indications for, 444.
methods of fitting, 446.
for amputation through thigh, apparatus with bearing upon ischium, 392.
without bearing upon ischium, 440.
combined mechanism for knee and ankle joints, 435.
conversion of articulated peg leg into leg with free knee movement and vice versa, 438.
peg leg and similar appliances, 408.
principles of, 392.
rules for, 392.
shape of top of bucket, 393.
suspension of thigh piece, 401.
walking with free flexion of knee. *See* Flexed Knee.
apparatus for, temporary and permanent, 383.
materials used in making bucket, 383.
Artificial limbs, arm. *See* Arm, artificial.
conditions to be considered in choice of, 381.
for disarticulation at hip joint, 444.

Artificial limbs, for disarticulation through shoulder joint and amputation through deltoid muscle, 523.
force transmitted by stump to, 382.
function of, 386.
hand. *See* Hand, artificial.
lower, bearing points for, 386.
general principles of fitting for, 386.
parts composing, 381.
and position of scar, 382.
preparing of flap for, 388, 389.
Artillery projectiles. *See* Projectiles, artillery.
Aspetic extractions, operative results of, 355.
Aubourg operation indicator for localisation of projectiles, 226.
Audioscopic finger-stall, 369.
Audition, functional examination of, 948.
blank for, used by Central Service of Oto-Rhino-Laryngology, 952.
cochlear reflexes, cochleo-phonatory reflex, 972.
cochleo-pupillary reflex, 977.
Lombard's test, 972.
false negative Rinne, 964.
Galton's whistle, 956.
hearing for the spoken voice, loud, 967.
preliminary investigation of, 949.
whispered, 972.
Lombard's assourdisseur, 963.
measurement of hearing-power, 951.
monochord, Struycken's, in, 956.
Rinne's test, 959.
Schwabach's test, 959, 964.
tests of reliability, 979.
Bourgeois', 993.
complete bilateral deafness, 980.
deaf-mutism, 980.
Escat's, with unisonant tuning forks, 990.
extreme bilateral dullness of hearing, 985.
Gosset's, 983.
Kern's, 989.
Lucae's, 989.
Audition, tests of reliability, Muller's, 989.
Stenger's, 990.
total unilateral deafness, 988.
by tuning fork, 954.
Weber's test, 959, 966.
Auditory hyperesthesia, due to labyrinthine concussion, 904.
Auditory meatus, external, wounds of, etiology of, 849.
pathological anatomy and symptoms of, 849.
treatment of, 850.
Auricle, wounds of, etiology of, 847.
symptoms of, 847.
treatment of, 848.
Auriculo-mastoid region, wounds of, complications of, ankylosis, temporo-maxillary, 872.
facial paralysis, 872.
lateral sinus and internal carotid, 873.
meningeal and cranial, 873.
treatment of, 679.
course of, 870.
diagnosis of, 873.
etiology of, 867.
frequency of, 867.
pathological anatomy of, 868.
penetrating, 868.
perforating, 868.
plunging, 868.
prognosis of, 874.
symptoms of, 870.
tangential, 868.
treatment of, for complications, 879.
early operative, 875.
in fracture of mastoid process, 876.
general indications for, 874.
immediate, 875.
infected wounds, 878.
for tangential wounds, 875.
Aviation, fitness for, 1034.
Axilla, projectiles in, 350.

Babinski electrical test, armamentarium for, 1016.
method of procedure, 1016.
principle of, 1016.
results of, in cases with diseased labyrinths, 1018.
in cases with normal labyrinths, 1018.

Babinski electrical test, semeiological value of, 1020.
Babinski-Weil test for equilibrium, 998.
Barany's tests, 1001.
advantages of, 1002.
caloric, 1008.
instruments required by, 1009.
physiological basis of, 1002.
rotation test, 1003.
diminution or abolition of reflex, 1005.
exaggeration, 1005.
result of, in normal person, 1004.
in a pathological condition, 1005.
Barium, platinocyanide of, 29.
Barret and Andrault process of localisation, 205.
Baths, hot, in treatment of joints, 728, 737.
Bathymeter, Dessane's, 197.
Bauer regulator, 17.
Bearing points, 386.
upon condyles of femur, 442.
upon end of leg stump, 457.
upon ischium, 393.
upon tuberosities of tibia, 447.
Béclère, M., and the knife process of localisation, 177.
and Morin's ready reckoner, 217, 219.
on the visual function in radiology, 31.
spintermeter, 19.
table, 78.
tattooing needles, 89.
Belot compass, 167.
localisation forceps, 158.
method of localisation, 212.
penetrometer, 28. (*Note.*)
table of, 78.
Benoist, M., 22, 26.
transparency tables of, 108.
Bertin Sans and Leenhardt process of graduated crosses, 212.
Binocular vision, essential principle of, 236.
Bistoury method of localisation, 245.
Blondin's tracing boards, 216. (*Note.*)
Bodies, transparency of, 27.
Bone, dead or decalcified, in packing of cavities, 665.
Bone, injuries of, radiography and, 58, 64.
Bone-grafting, 565–567, 575–576.
Bone inflammation, general principles of pathology of, 578.
results of, 578.
Bone tissue, elements of, 578.
Bones, long, parts of, 579.
wounds of, without complete fracture of cancellous bone, 608.
wounds of shaft of, 604.
Bony abnormalities, errors in reading of plates due to, 124.
Bony union, defects of, ankylosis due to, 547.
common to femur, 542.
constituting indications for treatment, 568.
delayed union, 561.
excessive formation of callus, 10.
false joints, 556.
in forearm, 547.
in gunshot fractures, 541.
in humerus, 548.
loss of bony substance, 556.
in lower limbs, 548.
orthopaedic boots for, 548.
osteomyelitis due to, 547.
osteotomy for, 549.
pseudarthrosis due to, 547.
shortening and angulation of fragments, 542.
use of radiography in, 557, 558.
delayed, 561.
differentiated from false joints, 556.
Borelli, 656.
Bouchacourt's fluoroscope, 84.
Bouchacourt's manudiascope, 300.
Bouget, 525, 531.
Boureau's appliances, 492.
Boureau's function of the artificial hand, 497.
Boureau's hook and ring, 504.
Boureau's length of artificial forearm, 498.
Braces, for amputation below knee, 453.
in amputation through leg, 453.
with extending sling, 423.
for suspension of artificial leg, 404.

Braces, for suspension of thigh piece, 404.
Brain projectiles, migration of, 271.
Bronchi, foreign bodies in, 258.
Brunet's grip, 487.
Bruning's test, technique of, 1012.
Brushmaker's hook, 499.
Bucket, for amputations through thigh, shape of top of, 393.
slope given to edges of, 394.
bearing points for, upon the base, 386.
direct end, 387.
upon surface of stump, 386.
fitting of, in artificial limbs not bearing on ischium, 440.
force transmitted to, by stump, 383.
leg, 447.
materials used in making of, 383.
Buguet and Gascard process of localisation, 208.
Bullets, cased, 132.
characteristics of, principal, 135–136.
glass, 108.
length and weight of, 131.
modern, 130 *et seq.*
table of characteristics of those used by principal powers, 134, 135.
Burns, modern treatment of, ambrine, 777.
chloride of iron, 785.
liquid paraffin, 784.
paraffin, asphalt, No. 21, 782.
paraffin seven of Major Hull, 777.
picric acid, 784.
substitute ambrine, 783.
Buscarlet, 677.
Buttock, projectiles in, 351.

Cadenat's apparatus for localising foreign bodies, 170.
Calcifications, errors in diagnosis due to, 257.
Calcified glands, 121, 257.
Callus, excessive formation of, 550–556.
due to defects of bony union, causes of, 550.
in infected fractures, 552.
interference of, with function of neighboring structures, 552.
in simple fractures, 550.
Callus, intermediate, 542, 544.
involvement of nerves in, 553–556.
provisional, of Dupuytren, 542.
Camus, Jean, 527.
Cardan joint, 506.
Caries of bone, operation on stump in presence of, 597.
Carotid region, projectiles in, 335.
Cased bullets, 131, 132.
Cassettes, 40.
Cathode, definition of, 1.
production of electrons from, 2.
Cathode pencil, 3.
aspect assumed by, 7.
Cathode radiation, 3.
Cathode rays, effect of on surface impinged by, 4.
See also Electrons.
Cavities of bone, duration of, 692.
methods of packing of, emulsions and pastes of inorganic nature in, 668.
antiseptic mixture of Neuber, 670.
Delbert's mixture, 676.
eugenol paste of Joüon, 675.
iodoform paste, 669, 670.
paste of Fantino and Valan, 674.
salol iodoforme, 669.
organic material, dead or decalcified bone in, 665.
sponges and non-bony substances in, 663.
to promote desirable action of soft parts, 687.
operation for obliteration of, technique of, 638. *See* Cavities and Tunnels in Bone.
Cavities and tunnels in bone, operation for, 678.
in ankylosis of joints with sinuses present, leading to epiphyses, 698.
complete removal of wall of bony cavity exposed by operation, 684.
in epiphyses and short bones, 696.
exploration of other sinuses, 681.
in flat bones, 698.
immobilisation, 683.
incision, 678.

Cavities and tunnels in bone, operation for, in large wound with moderate suppuration, 704.
opening up large groove or furrow in bone, 678.
in presence of foreign bodies in or near bone, 702.
removal of granulations, 680.
in shaft of bone surrounded by thick mass of muscle, as in femur and humerus, 694.
in shaft of long bone with extensive subcutaneous surface or border, 693.
time of, 705.
utilisation of soft parts, 686.
immediate collapse of soft parts against floor of newly formed groove, 690.
by packing, 687.
Cazin, 663, 664.
Centring the joint, 58.
C. G. S. system, 26 (note).
Chabaud tube, 6, 20, 73.
Chassepot, 130.
Chauffeur's bell, 505.
Chemical regulators, 16.
China ink, injected under skin, for localising important points on skin, 90.
Chinese shadowgraphs, 29.
Chloride of iron, in treatment of burns, 785.
Chlorine gas poisoning, venesection in, 775.
Cholesteatoma, 831.
treatment of, 839.
Cochlear reflexes, cochleo-phonatory, 972.
cochleo-pupillary, 977.
Colardeau process of radiographic localisation, 209.
Colardeau and Richard stereoscope, 239.
Combined mechanism for knee and ankle joints, 435.
Combined suspension for artificial leg, 406.
Compass, 166, 287, 322 *et seq.*
Belot, 167.
bibliography, 214 (note.)
Cadenat apparatus, 170.
Debierne, 167.
difficulties and causes of failure of, 289.
in extraction of projectiles, attitude for, 289.
Compass, in extraction of projectiles, description of, 287.
difficulties and causes of failure of, 289.
elasticity of tissues and muscular tonicity in, 290.
failures irremediable in, 291.
Hirtz, 294.
instruction not to separate lips of wound, 290.
Marion-Danion, 294.
mobile, 291.
muscular relaxation in, 289.
Saissi, 294.
Hirtz, 174, 207, 214, 234, 287, 294.
interpretation of plate, 216.
for radiographic localisation of projectiles, 214.
in localisation of projectiles, 166.
radiographic, 214.
regulation of, 218.
particularities concerning, 294.
regulation of, 218, 219.
Saissi, 170, 294.
sector-guide of Grandgérard, 169.
sterilisation of, 288.
surgical occasions for use of, 287.
Compound fractures, clinical study of, 625–647.
pathology of, 611–618.
radiographic study of, 619–624.
Condyles of femur, amputation through, 440.
Continuous electro-magnets, 359.
Contremoulins compass, 294.
Contremoulins and Rémy process of radiographic localisation, 209.
Convertible peg leg, 438.
Coolidge double anticathode tube, 248.
Coolidge tube, 20.
Corset, thigh, 453.
Cranial complications of auriculo-mastoid wounds, 873.
Crookes tube, 3.
in operation, 15.
Cross-thread localiser, 153.
Cryptoscope, description and use of, 82.
Curtillet, operation of, 575–576.
Curves, sinusoidal, 24.
Cylinder of bone, 579.
in osteomyelitis, 580.
Cylinder diaphragms, 43.
Cyrtometer, 161.

Danger as contra-indication to extraction, 276.
Dauvillier's ready reckoner, 232–233.
Deaf-mutism, clinical description of, 925.
course of, 927.
test for, 980.
Deafness, cerebral, 918.
complete bilateral, test for, 980.
due to wounds of tympanic membrane and cavity, 856.
ephemeral, 899.
examination for, results of, and preparation of report, 1024.
extreme bilateral dulness of hearing, test of reliability for, 985.
functional, 921.
hystero-pithiatism, 921.
simulation, 934.
functional examination of audition, 948.
labyrinthine. *See* Labyrinthine concussions.
from lesions of auditory nerve tracts, 916.
of bulb and isthmus of encephalon, 917.
cerebral, 918.
of trunk, 917.
and military fitness, 1033.
objective examination in, 945.
partial, 900.
simulation of, 936.
pithiatic. *See* Hystero-pithiatism.
previous histories in, 941.
simulation of. *See* Simulation of deafness.
total, simulation of, 935.
or almost total, 905, 928.
total unilateral, tests of reliability for, 988.
Debierne compass, 167.
Delayed union, treatment of, 561.
Delbert, 651.
mixture of, 676.
spring extension splint of, 721.
walking plaster splint of, 721.
Deltoid muscle, amputation through, artificial limbs for, 523.
Dermatitis, X-ray, 93.
Dessane fluoroscope, 84.
Dessane's double fluoroscope, 87.
Dessane's radio-bathymeter, 197.
Diagnosis, errors of, due to calcifications, 257.
Diaphragm, projectiles in, 261, 342.
Diaphragms, cylinder, 43.
use of, in radiography, 43.
Disarticulation at hip joint, artificial limb for, 444.
Discharge No. 1 for deafness, 1036.
Double image, localisation by, 175.
radioscopic methods of, 175.
using displacement of shadow without measuring it, 177.
including measurement of displacement of shadow, 184.
theoretical standpoint, 142.
Doyen's anatomical sections, 250.
Drault's aluminum cassettes, 40.
Dum-dum bullets, 132.
Dundas Grant's test for equilibrium, 1015.
Duplay, 663, 664.
Duplex foot, 434.
Dupuytren, fracture of, 558.
provisional callus of, 542.
Dura mater, injuries of, due to wounds of auriculo-mastoid region, 882.
Duval, Pierre, cited, 288, 289.

Ear, lesions of, and military fitness, acuteness of hearing and deafness, 1033.
for aviation, 1034.
external ear, 1030.
internal ear, 1033.
labyrinthine disturbances, 1033.
middle ear, 1030.
oto-rhino-laryngeal application form, 1031.
wounds of. *See* Wounds.
Eczema of external meatus, nature of, 817.
treatment of, 817.
Elbow, articulation at, for artificial arm, 519.
attachment of artificial forearm to, 465.
false joints, 570.
projectiles in, 269, 351.
Elbow joint, for above elbow amputations, 513.
for below elbow amputations, 471.
short stumps, 475.
concavity of armlet in, 470.
construction of, 473.
long stump, 473.

Elbow joint, construction of, short stump, 475.
ratchet to fix in flexed position for artificial arm, 513.
for worker's arm, 519.
Electric energy, high voltage source of, for production of X-rays, 8, 9.
utilization of, in production of X-rays, 9.
Electric explorer-extractor, 370 *et seq.*
Electric explorers and detectors, 370.
of Cambridge Scientific Instruments Co., 373.
electric explorer-extractor by Trouve, 370.
Guilloz' modification of Trouve apparatus, 371.
Henrard's modification, 372.
Electrical detection of projectiles, 364.
induction balance and its derivatives, 364.
Chilowsky's apparatus, 366.
Hughes' apparatus, 364.
Kaufmann's apparatus, 366.
searcher-localizer of Francois, 367.
Electricity, high-voltage sources, 8.
positive and negative, 5.
Electro-magnets, 359 *et seq.*
alternating or vibrating, in search for projectiles, 361.
continuous, search for projectiles by, 359.
Electro-therapeutics, 358.
Electro-vibrator, 166, 361.
Electrons, definition and size of corpuscles of, 2.
effect of, on surface impinged by, 4.
forces inducing deviation of, from rectilinear path, 7.
production of, 2.
production of X-rays from, 3.
projection of, 2.
speed of, dependent on difference in potential at terminals of tube, 23.
velocity of, 2, 3.
Elephant boot, 459.
Epiphyses, ankylosis of joints with sinuses leading to, operation for, 698.
cavities and tunnels in, technique of operation for, 696.
Equilibrium, in an artificial leg, 415.
functional examination of, Babinski's electrical test, 1016.
Babinski-Weil test, 998.
Barany's technique, 1012.
Brünings' technique, 1012.
calorie test, 1008.
Dundas Grant's technique, 1013.
hot water, 1014.
induced nystagmus. *See* Barany's tests.
objective examination beforehand, 1011.
oto-calorimeter of Brünings, 1009.
oto-goniometer, 1011.
preliminary examination, 996.
rotation test, 1003.
search for spontaneous nystagmus, 1001.
standing upright, 997.
walking with eyes open, 998.
walking with eyes shut, 998.
Eugenol paste in packing of cavities, 675.
Examination, objective, in war deafness, 945.
plane of, 48.
Excessive formation of callus, 550-556.
Eye, localisation of foreign bodies in, xvii.
localisation of projectiles in, 253.
removal of foreign bodies from xix.
Eyeball, projectiles of, 333.
Eyes, protection for, in X-ray examination, 84, 97.

Face, localisation of projectiles in, 253.
False joints, 556.
articular, 560.
cause of, in war surgery, 560.
characteristics of, 557.
differentiated from delayed union, 556, 559.
at elbow, 570.
at humerus, 568.
pathological type of, 561.
treatment of, 563 *et seq.*
with fragments in contact without loss of substance, 563.
grafting, 565.

False joints, treatment of, with loss of bone, 564.
means of, 563.
by open operation, 567.
use of radiography in, 557–559.
varieties of, 556.
Fantino, emulsion of, 674.
Federation leg, 413.
Femur, cavities and tunnels in, technique of operation for, 694.
defects of bony union common to, 546.
pseudarthrosis of, 573.
Fibula, avoidance of pressure on, 447, 448.
Filters, aluminum, 96.
Finger-stall, audioscopic, 369.
Flap, muscles of, becoming fibrous, 388.
preparation of, for artificial limb, 388, 389.
Flexed knee, angle of foot, 414.
artificial muscle with, 417.
conversion of articulated peg leg into and vice versa, 438.
design of, 413.
ensuring equilibrium, 415.
extending force of, 420.
extending slings, 423.
extension braces, attaching of to front of leg, 425.
knee-extending mechanisms, 417.
Marks, 419.
mechanism combined for knee and ankle joints, 435.
mechanism for limiting extension of knee, 418.
mechanism to secure rigidity of knee during weight bearing, 428.
mechanism for starting extension of knee during time leg is swinging, 417.
mechanism of walking with, 416.
movable ankle with, 430.
prevention of hyperextended position, 418.
stop to limit extension in, 418.
walking upon, 446.
Fluorescent screen, 82.
Fluorescence, principle of, 29
production of, in X-ray tubes, 13.
Fluoroscope, 82 *et seq.*
Bouchacourt's modification of, or manudiascope, 84.
Dessane's, 84, 87.
Fluoroscope, double, Dessane's, 87.
invented by Wullyamoz of Lausanne, 83.
Réchou's, 83.
use of hood with, 84.
wearing of dark-colored glasses in use of, 84.
Fluoroscopic image, 29.
Fluoroscopy, 29.
lights used in, 86.
See also Radioscopy.
Foot, in amputation through leg, with free knee joint, 456.
amputation of, of Chopart and Lisfranc, 461.
of fore part, 463.
construction of, 35.
with lateral mobility, 434.
with movable ankle, 430.
projectiles in, 271, 351.
Forceps, Belot's, 158.
right-angled, of Wullyamoz, 297.
Forceps method of localisation of projectiles, 158.
Forearm, artificial, artificial hand and appliances, 476.
attachment of, to elbow, 465.
to shoulder, 467.
concavity of armlet, 470.
constituent parts of, 464.
elbow joint, 470.
length of, for artificial hand or appliance, 498.
points of attachment, 463.
resistance to rotation, 469.
resistance to upward pressure, 469.
suspension of, 465.
defects of bony union in, 547.
projectiles in, 269, 351.
pseudarthrosis of, 572.
Foreign bodies, in or near bone, operation for, 702.
in eye, localisation of, xvii.
localisation of, general theory of methods of, 142.
mistakes regarding, 116.
other than projectiles, 356.
remaining imbedded in bone, 550.
search for, history of case and clinical examination, 99.
radioscopic examination, 102.
in regions distant from wound of entry, 101.
Fork rest, Raynal's, 489.

Formation of sequestra, 612–613.
Fracture, compound, with chronic sinuses, 611.
consolidation of fractured bone in, 614.
pathology of, 611.
processes of, 612.
separation of necrosed bone in, 612.
consolidation of, 542.
gunshot, defects of bony union in, 541.
mal-united, effect of, on action of neighboring joints, 739.
on ball-and-socket joints, 741.
on hinge joints, 742.
of humerus, 757.
of radius and ulna, resulting in limitation of range of supination, 759.
X-ray examination of, 64.
Fragments, angulation of, 542.
shortening of, 542.
in femur, 546.
Frees' foot and knee, 437.
Furuncle, diagnosis of, 809.
treatment of, 811.

Galton's whistle, in examination for deafness, 956.
Gas collapse, treatment of, 774.
Gas gangrene, deep, symptoms of, 764.
indications for amputation of an extremity with, 767.
onset of, 763.
treatment of, amputation, indications for, 767.
antitoxin, 768.
assisted by phenolizing of wound cavities, 766.
conservative measures, 766.
general, 766.
surgical, summary of, 767.
Gas infection, forms of, benign epifascial, 765.
malignant subfascial or intramuscular, 765.
frequency of, in wounds, 763.
local, symptoms, of, 764.
treatment of, 765.
surgical, summary of, 767.
Gas poisoning, chlorine, venesection in, 775.
first and second stages of, 769.
prevention of, 776.
symptoms of, 771.
Gas poisoning, treatment of, early, 774.
general, 775.
local, with internal oily applications, 774.
venesection, 775.
Gascard and Buguet process, 208.
Gases, poison, 769.
Gassing. *See* Gas Poisoning.
Geometrical triangulations, theory of, 142.
Glands, calcification of, 121, 257.
Glass bullets, 108 (note).
Gloves, X-ray, 97.
Graduated crosses, process of, 212.
Graft, in aseptic cases, 565.
autoplastic, 565.
heteroplastic, 565.
homoplastic, 565.
"taking of," 565.
ultimate fate of, 565.
Grandgérard's "sector-guide," 169.
Graph method of drawing, 216.
Gras rifle, 130.
Grashey apparatus, 295.
Gratuities, 792.
for deafness, 1036.
Grenades, 139.
Gripouilleau, agricultural hook and ring, 504–506.
ploughman's hand, 141, 521.
vine-dresser's hook, 492.
Gudin's localiser-guide, 197.
Guilleminot on the plane of examination, 48.
Guilleminot's radiogoniometer, 203.
Guilloz's tube with double anticathode, 229.
Gunshot fractures, chief characteristics of, 611.
defects of bony union in, 541.
Guyon's amputation, 458.

Hamilton, 663.
Hand, appliances for use in place of, 488.
agricultural laborer's ring, 506.
American chuck, 502.
with ball joints, 508.
with bayonet joints, 508.
brushmaker's hook, 498, 499.
"cardan" joint, 506.
fixed, 492.
horticulturist's hand, 494.
knife and fork, 489.
leather-cutter's hand, 496.
length of forearm for, 498.

Hand, appliances for use in place of, for manipulating a file, 502.
mechanic's hand, 497.
with mobile joints, 503.
packer's hand, 495.
plumber's hand, 495.
postman's hand, 493.
Raynal's fork rest, 490.
for special crafts, 498.
T-shaped clamp for holding tool handles, 501.
tram-driver's bell, 506.
vine-dresser's hand, 492, 493.
for workmen, 491.
artificial, 477.
and appliances, for use with artificial arm and ratchet, 517.
automatic fingers, 485.
automatic thumb, 478.
Beaufort thumb, 479.
Brunet's grip, 487.
for commercial travellers, 482.
shape of, 483.
spring grip thumb, 477.
utility of, 476.
projectiles in, 269.
Hand grenades, 139.
Handbook of Guidance and Reference, 771.
Hands, precautions for, in X-ray examination and operations, 97, 319, 320, 323.
Haret's method of localisation, 175, 188, 231.
Hauchamp's atlas, 66.
Head, extraction from, 328.
Head and neck, localisation of projectiles in, 251.
Headache, due to labyrinthine concussion, 904.
Hearing, acuteness of, and military fitness, 1033.
tests of. *See* Audition, functional examination of.
See Audition.
Heart, projectiles in, 342.
localisation of, 258.
Hedley process of localisation, 208.
Hedley and Mackenzie-Davidson process of localisation, 209.
Heliotherapy, 652.
Henrard's process of localisation, 212.
Henrard telephone apparatus, 373.
High-voltage currents, production of, 1.
High-voltage currents, sources, 8.
Hip, projectiles in, 270, 351.
Hip joint, disarticulation at, artificial limb for, 444.
Hirtz "localising compass," 174, 207, 214 *et seq.*, 234, 287, 294.
Hirtz stereoscope, 237.
Hirtz-Gallot pierced screen, 182, 231.
Histories, previous, in war deafness, 941.
Hook and ring, agricultural, 504.
Boureau's, 504.
Hot baths, 728, 737.
Humerus, cavities and tunnels in, technique of operation for, 694.
false joints at, 568.
mal-united fractures of, effects of, on range of movements of shoulder joint, 757.
shortening of fragments of, 548.
Hyperostosis with chronic sinus, 626-631.
Hysteria, ix.
traumatic, 780 *et seq.*
Hystero-pithiatism, clinical description of, deaf-mutism, 925.
dulness of hearing, 929.
total or almost total deafness, 928.
definition of, 921.
etiology of, 922.
examination for, 930.
prognosis of, 929.
treatment of, 930.
abrupt, 932.
after failure of first attempt, 932.
neurological clinics for, 933.
re-education, discreet, 933.
success in, 932.

Iliac fossa, internal, projectiles in, 346.
Immobilisation of joints, indications for, 716.
normal, resulting in stiffness, 720.
prophylaxis of, 716–724.
treatment of, 725–738.
Incision, to approach bone in musculo-spiral involvement, 553.

Index finger, length of, 482.
Induction balance, and its derivatives, 364.
description of, 364.
Induction balance coil, 68.
Infantry projectiles, 129.
Infantry rifle, 130.
Infected wounds, treatment of, xiii.
Infection, primary, recrudescence of, 541.
Inflammation of bone. *See* Bone inflammation.
Injuries of the bone, 58, 64.
Ink marker, 91.
Installations, 68.
portable, 70.
Instantaneous metrical gauge, 242.
Instruments for mechanical guiding, 166.
Intensifying screens, 38, 40.
use and abuse of, 41.
Intermittent control, extractions with, 302.
method of, 323.
Intrapulmonary projectiles, 336.
Iodoform, a cause of photographic errors, 118.
Iodoform paste, 669.
in packing of cavities, 669.
Mosetig Moorhof's, 670.
experiments to replace iodoform with other antiseptic, 673.
results of, 674.
Iris diaphragm of Béclère, 43.
Isch-Wall, 669.
Ischio-rectal fossæ, projectiles in, 350.
Ischium, apparatus with bearing upon, 392.
artificial limbs not bearing on, 440.
preparation of, for artificial limb, 393.
Jackson's tube, 4.
Jaugeas, M., 28.
process of localisation of, 190.
Johnson, Hernaman, method of localisation of projectiles, 160.
Joint, centring of, 58.
shoulder, effects of mal-united fractures of humerus on, 757.
Joints, after-effects of wounds in, 707.
Joints, ankylosis of. *See* Ankylosis.
ball and socket, effect of mal-united fractures on, 751.
effect of mal-united fractures on neighboring, 739.
false. *See* False Joints.
hinge, effect of mal-united fractures on, 742.
movable projectiles in, 272.
muscles of, lesions of, 711.
treatment of, 726.
stiffness of. *See* Stiffness of joints.
tendons of, lesions of, 711.
treatment of, 726.
Jollant and Warluz method of localisation, 228.
Joüon, eugenol paste of, 135.

Knee, bent, walking on, 446.
flexed. *See* Flexed knee.
Marks, 419.
method for attaching extension braces to front of leg, 425.
pinching of flesh behind, in flexion, 449.
projectiles in, 271.
Knee and ankle joints, combined mechanism for, 435.
Knee-extending mechanisms, 417.
Knee-extending sling, 423.
Knee joint, amputation through, 440.
for amputation through the leg, 453.
free, in amputations through leg, appliances with bearing upon tuberosities of tibia, 447.
appliances with end bearing only, 457.
foot, 456.
methods of fitting, 447.
Knife process of localisation, 177.

La Baume-Pluvinel's telephone probe, 166.
Labyrinthine concussion, due to direct violence to cranium, cerebellum alone affected, 892.
course of, 886, 890.
diagnosis of, 890.
etiology of, 883.
labyrinth alone affected, 891.
labyrinth and cerebellum both affected, 893.

Labyrinthine concussion, due to direct violence to cranium nature of lesion, 885.
pathogenesis of, 886.
pathological anatomy of, 884.
prognosis of, 890.
seat of lesion, 884.
symptoms of, 888.
treatment of, 893.
from explosions, 894.
diagnosis of, differential, 909.
by lumbar puncture, 907.
positive, 906.
etiology of, 895.
determining causes, 897.
predisposing causes, 896.
vicarious rôle of rupture of tympanic membrane, 897.
frequency of, 895.
pathological anatomy of, 897.
prognosis of, 906.
symptoms of, ephemeral deafness, 899.
partial deafness, 900.
total or almost total deafness, 905.
treatment of early, 940.
later, 911.
preventive, 914.
Labyrinthine disturbances, and military fitness, 1033.
Lavialle, A., operation indicator of, 226.
Lead bracelet, 284.
glass spectacles, 97.
Leather-cutter's hand, 496.
Leclainche, 649.
Leenhardt and Bertin Sans process of graduated crosses, 212,
Le Faguay's process of localisation. 178.
Leg, artificial, for amputation through thigh. *See* Thigh.
with free knee joint, appliances with bearing upon tuberosities of tibia, 447.
appliances with end bearing only, 457.
methods of fitting, 446.
indications for, 444.
peg, 409.
projectiles in, 271, 351.
pseudarthrosis of, 574.
Leg bucket, 447.
material for, 448.
shape of, 447.
Le Maréchal and Morin process of localisation, 179.
Lighting, in extraction of projectiles with aid of intermittent control, 306.
Limbs, projectiles in, 276 *et seq.*
Lister, Sir J. (Lord), x.
Liver, projectiles in, 343.
Localisation, accuracy in, 149.
anatomical, abdomen, 264.
arm, fore-arm and hand, 269.
bronchi, 258.
calcifications, 257.
diaphragm, 261.
extraction of projectiles by, 285.
eye, 253.
face, 255.
foot, 271.
head and neck, 251.
heart, 258.
hip, 269.
knee, 271.
leg, 271.
lower limb, 269.
migration of projectiles, 271.
necessity of, 249.
neck, 254.
pelvis, 267.
pericardium, 258.
and pulsatory projectiles, 257.
shoulder, 267.
skull, 251.
spine, 265.
thigh, 269.
thorax, 254.
trachea, 258.
upper limbs, 267.
anatomo-clinical, 251.
deductions useful in radioscopic examinations, 143.
by double image, radioscopic methods of. *See* Radioscopic methods of localisation.
forceps, 158.
general theory of methods of, 142.
law on which methods are based, 142.
by means of tube with double anticathode, 226.
methods of, 144.
errors in, 149, 150.
resting on theory of geometrical triangulations, 143.
physical problem of, 150.
practical conclusions on, 230.

Localisation, radiographic. *See* Radiographic processes of localisation.
radioscopic. *See* Radioscopic methods of localisation.
See also Projectiles, localisation of.
Londe process of localisation of projectile, 192.
Lower limbs, shortening of fragments in, 548.
Lumbar vertebræ, examination of, 123.
Luminous adaptation, 32.
law of, 32.
Luminous sensitiveness, 31.

Mackenzie-Davidson and Hedley process of radiographic localisation, 208.
Mackie, 667.
Magnetic projectiles, search for, 359.
by alternating or vibrating electro-magnets, 361.
by continuous electro-magnets, 359.
Magnets, xxv.
classification of, 359.
natural, 359.
in search for projectiles, 359.
Malingering, 780.
cases of, 804.
Malunion of femur, 753–757.
of fractures, effects on ball-and-socket joints, 751 *et seq.*
on hinge-joints, 742.
of humerus, 746, 757–759.
of radius and ulna, 547, 747–748, 759–761.
of tibia, 748–750.
Manudiascope, 84.
Bouchacourt's, 300.
Marion-Danion compass, in extraction of projectiles, 294.
Marion-Danion marker for localisation of projectiles, 224.
Marks' braces, 425.
Marks' knee, 419.
method for attaching extension braces to front of leg in, 425.
Marks' knee joint, 421.
Marks' leg, 414.
Martini-Henry rifle, 130.
Mary Mercier process of localisation, 204.
Mattey stereo-telescope, 238.
Massage, abuse of, 707.
contra-indications for, 727, 737.
in treatment of joints, 737.
Mastoid process, fracture of, treatment of, 876.
Mastoiditis, chronic, 834.
traumatic, with integrity of meatus and tympanum, treatment of, 878.
with laceration of membranous meatus and integrity of tympanum, 879.
with traumatic median otitis, treatment of, 879.
Materials for artificial arms, 464.
for bucket, 383.
Mauclaire, M., operations in the dark, 300.
Mauclaire's opaque paste for the hands, 320.
Maxillary sinus, projectiles in, 335.
Maxillary-pharyngeal region, projectiles in, 335.
Mazérès rule, 192.
Mediastinum, projectiles in, 341.
Medical reports, drawing up of, 939.
results of examination in preparation of, 1024.
Medico-legal considerations, disposal of wounded after cure, methods of, 787.
pensions and gratuities, 792.
refusal of treatment, 799.
instruction relative to course of action necessitated by, 801.
when may cure be considered accomplished, 790.
Medullary canal, 579.
in osteomyelitis, 380.
Meningeal complications of auriculo - mastoid wounds, 873.
Menuet's process of localisation, 156, 161.
Mercier process of triangulation, 204.
Mergier process of localisation, 209, 228.
Metrical gauge, instantaneous, 242.
"Mexican" stereoscopes, 238.
Migration of projectiles, 271.

Milliampèremeter, 9. (*Note.*)
Milliampères, definition of, 9.
Military fitness, for aviation, 1034.
  lesions of ear and. *See* Ear, lesions of, and military fitness.
Minié rifle, 130, the,
Mobile projectiles, 291.
Mobilisation, forcible, 733.
  gradual, 730.
  by mechanical means, 729.
  of stiff joints, 728 *et seq.*
    contra-indications to, 727.
    gradual, by surgeon, 730.
    mechanical, 729.
    methods of, 728.
  by a succession of plasters, 735.
Monochord, Struycken's, in examination for deafness, 956.
Morin and Béclère's, ready reckoner, 217, 219.
Morin and Le Marechal, localisation process and apparatus of, 179.
Morize process of localisation of projectiles, 159.
Mosetig Moorhof, paste of, 710 *et seq.*
Mouchet, 650.
Muscles, after-effects of wounds in, 707.
  of joints, lesions of, 711.
    treatment of, 726.
Muscular relaxation, 289.
Muscular tonicity, 290.

Neck, extraction of projectiles from, 328.
  localisation of projectiles in, 254.
  search for foreign bodies in, 123.
Necrosis, associated with osteomyelitis, 580.
  of bone, operation on stump in presence of, 597.
Needle-carrier explorer, an electric, 372.
Needle process of extraction of projectiles, 285.
Needle rifle, 130.
Nerve, compression or irritation of, 554.
  division of, 554.
Nerves, projectiles in, 352.
Neuber, paste of, 670.
Neuromata, amputation. *See* Amputation neuromata.
Non-union, treatment of, 561.
Normal ray, definition of, 48, 49.
  importance of, in X-ray interpretation, 55.
  point of issue of, 56.
Nove Josserand, 525, 531.
Nyrop's grip, 501.
Nystagmus, induced, 1001. *See* also Barany's tests.
  spontaneous, search for, 1001.

Objective examination in war deafness, 945.
Oblique rays, 59.
Obliteration of cavities and tunnels in epiphyses and short bones, 696 *et seq.*
  in femur, 694–695.
  in fibula, 696.
  in flat bones, 648.
  in humerus, 694–695.
  in radius, 696.
  in tibia, 693.
  in ulna, 693.
  operation for, 678 *et seq.*
Ochotin, 667.
Ollier, 655–656, 658, 660.
  osteogenetic layer of, 579.
Ombrédanne retracting forceps, 305.
Operating theatres, locality, 305.
  preparation of the patient, 307.
  preparation of the room and region, 308.
  question of lighting, 306.
Operation indicators, 226.
Operative damage in extraction, 277.
Orbit, projectiles of, 333. *See also* Eye.
Orthodiagraphy, 61.
Orthogonal projections, 61.
Orthopædic boots for shortening in lower limbs, 548.
Orthoscopic stereoscopes, 238.
Osmo-regulator, 17.
Ossiculectomy, 845.
Osteitis, with granulations and polypi, 831.
  superficial, 831.
Osteoclasis, in defects of bony union, 550.
Osteogenesis by substitution, 661.
Osteomyelitis, chronic traumatic, in amputation stumps requiring further operation, 582.

Osteomyelitis, chronic traumatic in amputation stumps requiring further operation, appearance radiographically, 589.
appearance of stump in, 590.
condition in, resembling spina ventosa, 589.
with moderate infection, 582.
operations necessary to bring about final healing in preparation for artificial limb, 595.
with osteosclerosis, 587.
with recurring ulceration, 585.
with severe infection, 584.
accompanied by necrosis and caries, 586.
sub-periosteal bone becoming excessive in, 588.
with suppuration, 594.
associated processes, necrosis, 580.
rarefaction, 582.
clinical study of, 625.
in compound fractures with chronic sinuses, 611.
course of, 644.
due to defects of bony union, 547.
duration of, 644.
effect of, on various parts of bone, 580.
general considerations on, 578.
radiographic study of, 619.
sinuses resulting from wounds of bone and compound fractures, 602.
termination of, 644.
treatment of, complete resection, 655.
defective, 648, 654.
by insertion of small drains, 648.
mineral waters in, 652.
Ollier's mere excavation of diseased bone, 655.
operation for obliteration of cavities and tunnels in bone, technique of, 678.
organisation of clot, 659.
osteogenesis by substitution, 661.
packing of cavities. *See* Cavities of bone.
by physiotherapy, 651.
by polyvalent serum, 649.
spontaneous ossification of cavity, 656.
Osteosclerosis, in amputation stumps, 587.
Osteotomy, in overlapping and angulation of fragments, 549.
Otitis, acute diffuse external, clinical picture of, 814.
definition of, 814.
diagnosis of, 815.
treatment of, 815.
acute suppurative median, duration of, 821.
suspected, 819.
symptoms of, 820.
treatment of, 820.
chronic suppurative median, accessible lesions of, 832.
advisability of specialist for, 823.
attico-antral suppurations with perforation in Shrapnell's membrane, treatment of, 840.
attico-tympanic suppuration, 828.
central perforation, 829.
cholesteatoma, 831.
treatment of, 839.
and chronic mastoiditis, 834.
complete loss of tympanic membrane, 829.
diagnosis of, in general, 823.
according to localisation, 826.
according to stage and extent of lesion, 831.
diagnosis of severity of, 834.
differentiated from tuberculous, 835.
granulations and polypi, 831.
treatment of, 838, 839.
inaccessible lesions of, 832.
lesions of ossicles, 832.
of mucous membrane, 831.
osteitis, 831.
perforation of Shrapnell's membrane, 830, 832.
types of, 833.
postero-superior perforation, 828.
suppuration in attic and attico-antral, 830.
therapeutic indications, 368.

Otitis, chronic suppurative median, treatment of, attico-antral suppurations with perforation in Shrapnell's membrane, 840.
atticotomy, operative technique of, 840.
cases with tendency to become worse, 837.
cholesteatoma, 839.
curative, 836, 839.
fleshy granulations, 838.
opening up of petromastoid cavity, 839.
partial, 840.
ossiculectomy, 845.
palliative, 837, 638.
post-operative, 843.
results of, 844.
severe forms of, 836.
simple forms, 836.
tympanic suppuration, 829.
external, acute diffuse, 814.
eczema, chronic, 817.
induced, 816.
furuncle, 809.
diagnosis of, 809.
treatment of, 811.
induced external, nature of, 816.
treatment of, 816.
non-traumatic, 809.
Oto-calorimeter of Brünings, 1009.
Oto-goniometer, 1011.
Otorrhagia, due to wounds of tympanic membrane and cavity, 856.

Packer's hand, 495.
Packing of bony cavities. *See* Cavities of bone.
Pain as an indication for operation, 273.
Paraffin, asphalt, No. 21, 782.
application of, 782.
physical factors of, 782.
liquid, in treatment of burns, 784.
seven of Major Hull, effects of, 781.
formula for, 779.
method of treatment with, 780.
results of, 778.
Paralysis, facial, due to auriculo-mastoid wounds, 872.
treatment of, 879.
Parinaud, Dr., 32.
research work of, 301.
Peg leg, 408.
articulated, conversion of, into leg with free knee movement and vice versa, 438.
conversion of, into leg with free knee joint, 438.
with joint at knee, 409.
jointed, 408.
fitting of transverse joint in, 409.
locks of, 410, 411.
principle of, 409.
old-fashioned, 408.
rigid, 401.
defects of, 409.
shape of leg piece, 410.
with show leg and foot, 411.
Pelvis, projectiles in, 267, 348, 350.
Penetrometer, Belot's, 28 (note).
Pensions, 792.
for deafness, 1036.
Pericardium, localisation of projectiles in, 258.
Perineal concavity, 395.
Periosteum, 579.
in osteomyelitis, 580.
Permeability of bodies by X-rays, 21.
Phenolising of wound cavities in gas gangrene, 766.
Phosphorescent bodies influenced by X-rays, 29 (note).
Photographic plate, action of X-rays on, 34.
negative and positive, 34.
Picric acid, in treatment of burns, 784.
Pierced screen of Hirtz and Gallot, 182.
Pierre process of triangulation, 204.
Pilon tube, 6.
Pirie stereoscope, 238.
Plates, importance of technical faultlessness in, 113.
interpretation of, 216.
number of, 114.
reading of, 113.
causes of error in region of lung, 121.
fictitious projectiles, 116.
Hirtz compass in, 216.

Plates, reading of, and incompetence of radiologist, 117.
of lower limb, 124.
of neck and lumbar vertebrae, 123.
for shape and nature of projectile, 114.
of shoulder, 124.
and photographic imperfections, 117.
and shadows cast by abnormal bony growths, 120.
by articles of clothing, 118.
by bony abnormalities, 124.
by dental devices, 119.
by "fillings" of bony cavities with iodoform, 120.
by iodoform, 118.
by medicaments of high atomic weight, 119.
by metal bodies introduced into the organism by the surgeon, 120.
by multiple calcified glands, 121.
by pathological concretions, 121.
of skull, 123.
of thorax, 124.
and written interpretation, 126.
Platinocyanide of barium, bodies rendered fluorescent by, 29.
Plumber's hand, 495.
Postman's hand, 493.
Pravas needle, for localising important points on skin, 90.
Precision method of localisation, 240.
Pressure, upward, resistance to, by artificial elbow, 469.
Previous histories in war deafness, 941.
Projectiles in abdomen and abdominal cavity, 264, 343, 346.
anatomical localisation of, 249.
anatomical situation of, 279.
in the arm, 269, 351.
artillery, description of, 137, 139.
description of action of, 139.
effects of, 140.
general action of, 137.
grenades, 139.
modification in, 137.
shells, 137, 139.
in axilla, 350.
Projectiles in buttocks, 351.
in carotid region, 335.
characteristics of, determined by principal diameter, 61.
complications associated with, abscesses, 353.
splinters, 355.
definition and characteristics of, 358.
in diaphragm, 261, 342.
effects of, artillery, 140.
cased bullets, 132.
fired base foremost, 133.
from small projectiles, general, 134.
from surgical standpoint, 129.
in elbow, 269, 351.
electrical detection of, induction balance and its derivatives, 364.
extraction of, from abdomen, 343.
from abdominal cavity, 346.
with aid of intermittent control, 302.
advantages of this method, 322.
criticisms on, 324.
difficult cases of, 321.
first control, 315.
inherent dangers as regards absorption of rays, 317.
lighting in, 306.
locality for, 305.
necessary radiological instruments, 303.
the point, 310.
preparation of patient, 307.
preparation of region, 308.
preparation of room, 308.
second control, 316.
statistics on, 324.
from arm, 351.
from axilla, 350.
from buttocks, 351.
from carotid region, 335.
conditions unfavorable to, 277, 280.
contra-indications to, 276.
danger of, 276.
from diaphragm, 342.
from elbows, 351.
from eyeball, 333.
first control, 315.
from foot, 351.
formula for, 280.

Projectiles, extraction of, from hand, 351.
from head and neck, 328.
from heart, 342.
from hip, 351.
historical review on, 295.
from iliac fossa, internal, 346.
indications for, according to region of body, 327.
from intracranial regions, 325.
from intrapulmonary regions, 336.
from intraspinal regions, dorsal and lumbar, 349.
from ischio-rectal fossæ, 350.
from knee, 351.
from leg, 351.
from limbs, 350.
from liver, 343.
from maxillary-pharyngeal region, 335.
from mediastinum, 341.
necessary radiological instruments, 303.
from neck, 328.
from nerves, 352.
operative damage from, 277.
operative results of, 355.
from orbit, 333.
from perineum, 350.
"the point," 310.
precautions, 317, 318.
processes of, 284.
with aid of intermittent control, 302.
with aid of intermittent control of screen, 307.
by anatomical localisation, 285.
of certainty, 295.
chance, 284.
compared, 322.
with a compass, 287.
continuous electro-magnets, 360.
in the dark, 300.
Grashey's, 295.
Mauclaire's, 300.
Mouchet's, 302.
needle process, 285.
Petit's, 302.
precision, 287.
of Rechou, 300.
in red light, 501.
under the screen, 295.
two images in perpendicular plane, 284.
of Wullyamoz, 297.
Projectiles, extraction of from pterygoid and maxillary-pharyngeal regions, 335.
regions to be avoided, 328.
route of access, according to region of body, 327.
from sacrum, 349.
under screen, 295.
second control, 316.
from spine, 348.
statistics, 324.
from sub-scapular region, 350.
from thigh, 351.
from thorax, 336.
from vessels, 352.
in eye and eyeball, 253, 333.
in face, 253.
fictitious, due to abnormal bony growths, 120.
due to articles of clothing, 118.
due to bony abnormalities, 124.
due to dental devices, 119.
due to "fillings" of bony cavities with iodoform, 120.
due to incompetence of radiologist, 117.
due to iodoform, 118.
in lower limb, 124.
due to medicaments of high atomic weight, 119.
due to metal bodies introduced into the organism by the surgeon, 120.
due to multiple calcified glands, 121.
in neck and in lumbar vertebræ, 123.
due to pathological concretions, 121.
due to photographic imperfections, 117.
in region of lung, 121.
in shoulder, 124.
in skull, 123.
in thorax, 124.
in foot, 271, 351.
in forearm, 269, 351.
in head, 251.
in heart, 258, 342.
in hip, 270, 351.
in iliac fossa, 346.
infantry, 129.
bullets, cased, 132.
length of, 131.
weight of, 121.
course traversed by, contusion zone, 134.

Projectiles, infantry, course traversed by, perforation zone, 134.
zone of typical explosive effects, 133.
effects of, general, 134.
of machine guns, 136.
movements of, abnormal, 131.
propulsive, 131.
rotary, 131.
for practising purposes, 136.
shapes of, 130.
table of characteristics of rifle bullets of principal powers, 134, 135.
intracranial, 328.
intrapulmonary, 336.
in ischio-rectal fossæ, 350.
in joints, 272.
in knee, 271, 351.
in leg, 271, 351.
in limbs, 267, 350.
in liver, 343.
localisation of, anatomical. *See* Localisation, anatomical.
bibliography for, 172.
choice of methods, 230.
compass, 166.
Belot, 167.
Cadenat apparatus, 170.
Debierne, 167.
Hirtz, 214.
Saissi, 170.
sector-guide of Grandgérard, 169.
by dimensions of its shadow, 156.
by double image, advantages of, 173.
Allaire radioscopic marker, 190.
Haret process, 188.
Jaugeas process, 190.
Londe process, 192.
practise in, on fictitious foreign bodies, 175.
radioscopic methods, 175.
using displacement of shadow without measuring it, 177.
including measurement of displacement of shadow, 184.
screen methods based on, 174.
forceps method of, Belot's, 158.
general considerations of, 151.
Projectiles, localisation of, general theory of methods of, 142.
historical survey of, 153.
by images on a single plane, 65.
images in various planes, 65.
importance of choosing a rapid convenient method for, 156.
according to intersecting axes, 157.
according to Johnson, Hernaman, 160.
maintaining same incidence in relation to plane of projection, 48.
Menuet process, 161.
necessity of having images in two directions at right angles, 64.
by non-radiological methods, 358.
electric explorers and detectors, 370.
electrical, 364.
magnetism, 359.
principal aim of, 156.
radiographic, 207.
Aubourg operation indicator, 226.
Belot method, 212.
Bertin Sans and Leenhardt process, 212.
Buguet and Gascard process, 208.
Colardeau process, 209.
compass for, 214.
Contremoulins and Remy process, 209.
Mackenzie-Davidson and Hedley process, 208.
Marion - Danion marker, 224.
by means of a tube with a double anticathode, 226.
Mergier, 209.
Mergier process, by means of tube with double anticathode, 228.
radiography and radioscopy compared, 154.
radiological forms, 234.
by radioscopic examination, 102.
Barret and Andrault process, 205.

Projectiles, localisation of, radioscopic, localiser - guide of Gudin, 197.
Mazérès rule and its simplification of the calculation, 192.
particular cases of triangulation, 202.
Pierre process, 204.
radio - bathymeter of Dessane, 197.
Roussel process, 203.
skiameter of Viallet and Dauvillier, 194.
Strohl and Mary Mercier processes, 204.
radioscopic methods advocated, 156.
by radio-stereoscopy, 239.
precision method, 240.
by stereometry, 240.
superfluity of methods of, 152.
variety of methods for, 155.
Vergely method, 164.
located in regions distant from wounds of entry, 101.
magnetic, search for, by alternating or vibrating electro-magnets, 361.
by continuous electro-magnets, 359.
in mediastinum, 341.
migration of, 271.
in brain, 271.
in serous membranes and joints, 272.
mobile, 291.
mutilating power of, measurement of, 129.
nature of, importance of knowledge of, 128.
in neck, 254, 328.
in nerves, 352.
in pelvis, 267, 348, 350.
in pericardium, 258.
in pterygoid region, 335.
pulmonary, 336.
pulsatory, 257.
radio-diagnosis of, and point of issue of normal ray, 36, 57.
in serous membranes, 272.
shape of, 141.
shape and nature of, in X-ray plates, 114.
in shoulder, 267.
Projectiles, size of, found in wounded, classification of, 140.
in skull, 251
in spine, 265, 348.
in sub-scapular region, 350.
surgical route of access, 280.
in thigh, 270, 351.
in thorax, 254, 336, 351.
in trachea, 258.
undiscovered, 100.
in vessels, 352.
visibility of, on screen, 105.
depending on apparatus, 105.
depending on nature of bodies looked for, 107.
depending on operator, 109.
in the wrist, 351.
Projection, laws of, 46 *et seq.*
plane of, 48.
orthogonal, 61.
Projections and the normal ray, 46 *et seq.*
Pseudarthrosis, due to defects of bony union, 547.
of femur, 573.
of forearm, 572.
of humerus, 570.
indications for treatment in, bone by bone, 568.
of leg, 574.
of radius and ulna, 573.
of tibia, 574.
Pseudoscopic stereoscopes, 238.
Pterygoid region, projectiles in, 335.
Pulsatory projectiles, 257.

Radiation, secondary, 41.
Radio-bathymeter of Dessane, 197, 231.
Radiochromism, 27.
Radiochromometer, 26.
formation of, 27.
power of penetration of radiation emitted by a tube not absolutely expressed by, 28.
a radiograph of, 28.
theoretical considerations for use of, 26.
Radiodermatitis, 318.
Radio-diagnosis of projectiles, point of issue of normal ray, 56, 57.
Radiogoniometer, Guilleminot's, 203.

Radiographic apparatus, 68.
accessory material, for localising important points on skin, 89.
various, 91.
viewing box, 88.
for conducting examination, 75.
cryptoscope, 82.
screen, 82.
standing up and lying down, 76.
tube stand, 76.
X-ray surgical table, 79.
X-ray table, 76.
installations, 68.
portable, 70.
shields and tube holders, 74.
tubes, 73.
Radiographic appliances, 87.
Radiographic examination, 112.
necessity of written interpretation, 125.
result of, and written interpretation, 125.
Radiographic processes of localisation, 207.
advantages of radioscopic processes over, 222
Aubourg operation indicator, 226.
Belot method, 212.
Bertin Sans and Leenhardt, 212.
Buguet and Gascard, 208.
choice of methods, 230.
Colardeau process, 209.
as compared with radioscopic, 222.
compass for, 214.
Hirtz, 214.
reading of plate, 216.
regulation of, 218.
Contremoulins and Remy process, 209.
Mackenzie-Davidson and Hedley, 208.
Marion-Danion marker, 224.
by means of a tube with a double anticathode, 226.
Mergier process, 228.
Mergier, 209.
Radiographic study of traumatic osteomyelitis, 619.
Radiographic technique, 113.
Radiographs, definition of, 34.
examination of, 35.
interpretation of, 35.
rules for, 35.
Radiography, 34.
appearance of osteomyelitis under, 589.
compared with radioscopy, 154.
in diagnosis of auriculo-mastoid wounds, 874.
indications for, 44.
instantaneous, 41.
and intensifying screens, 40.
rapid, 41.
slow, 41.
time of exposure in, 38.
use of, in defects of bony union, 557, 558.
use of diaphragms in, 43.
very rapid, 41.
Radiological localisation forms, 234.
specimen of, 234.
Radiology, stereoscopic reproduction in, 235.
visual function in, 31.
luminous sensitiveness, 31,
visual sensitiveness, 33.
war, maintaining same incidence in relation to plane of projection, 48.
Radio-profundometer, Réchou's, 161.
Radioscopic apparatus for direct reading, 203.
Radioscopic examination, 102.
deductions useful in, 143.
factors in favour of, 155.
for foreign bodies, 102.
prejudice against, and reasons for, 103.
result of, and written interpretation, 125.
visibility of projectiles on screen, 105.
depending on apparatus, 105.
depending on nature of bodies looked for, 107.
depending on operator, 109.
Radioscopic marker, 190.
Radioscopic methods of localisation, advantages of, over radiographic, 222.
Barret and Andrault process, 205.
choice of methods, 230.
by double image, 175.
using displacement of shadow without measuring it, 177.
knife process, 177.
Le Faguays process, 178.
localiser-guide of Gudin, 197.

Radioscopic methods of localisation by double image, Mazérès rule and its simplification of the calculation, 192.
including measurement of displacement of shadow, 184.
Allaire radioscopic marker, 190.
displacement of tube, 187.
distance from anticathode to screen, 186.
Haret process, 188.
Jaugeas process, 190.
Londe process, 192.
Morin and Le Marechal, process and apparatus of, 179.
pierced screen of Hirtz and Gallot, 182.
radio-bathymeter of Dessane, 197.
skiameter of Viallet and Dauvillier, 194.
particular cases of triangulation, 202.
Roussel process, 203.
Pierre process, 204.
Strohl and Mary Mercier processes, 204.
Radioscopic receptivity, 296.
Radioscopic technique, 110.
Radioscopic visibility, 105, 155 *et seq.*
Radioscopy accuracy of, 154.
advantages of, over radiography, 174.
compared with radiography, 154.
dangers to the operator, 154.
Debierne method of localising foreign bodies, 162.
in diagnosis of auriculo-mastoid wounds, 874.
explanation of, 29.
historical survey of, 153.
indications for, 44.
Menuet process of localising foreign bodies, 161.
objections against, 154.
and radiography, 44, 153.
starting point of, 29.
use of, gaining ground over radiography, 154.
Vergely method of localising foreign bodies, 164.
See also X-ray.
Radiostereometer, Tauleigne-Mazo's, 241.
Radio-stereoscopy, 235 *et seq.*
cross-wire method, 244.
double anticathodal tube applied in, 245.
difficulties of, 247.
water-cooled, which can be placed under radiological table, 248.
history of, 235.
instruments used in, instantaneous metrical gauge, 242.
radiostereometer, Tauleigne-Mazo's, 241.
stereometer, 241.
stereoradiographic scale, 242.
stereoscopes, 237, 238.
stereothesimeter, 242.
obtaining of contrast in, 238.
precision method of localisation by, 240.
principles of, 244.
problem of, 236.
process of, 237.
in search for and extraction of projectiles, 239.
utilisation of, 243.
Radio-surgery, conducting of, in absence of competent radiologists, 85.
lights used in, 86.
Radio-surgical apparatus, portable, 70.
Radius, mal-united fractures of, resulting in limitation of range of supination, 759.
Rarefaction, associated with osteomyelitis, 582.
Ratchet, to fix elbow joint in flexed position, 513.
Ray, normal, definition of, 48, 49.
importance of, in X-ray interpretation, 55.
point of issue of, 56.
Réchou's fluoroscope, 83.
Réchou's radio-profundometer, 161.
Recrudescence of infection, 549, 598.
of primary infection, 541.
osteotomy for, 549.
Re-education, advantages of using temporary limb in, 531.
of amputation cases, 145.
choice of trade in, 532, 534, 535.
for deafness, 913.

Re-education, discreet, for hysteropithiatism, 933.
general principles in, 525.
good-will of patient a necessity in, 527.
intelligence and will as factors in, 533.
law as affecting, 528.
necessity of, 526.
partial resumption of work, 528, 529.
no connection with pension, 528.
possibilities of, 533.
special workshops for, 530.
Refusal of treatment, 775.
Regulators for X-ray tubes, air, or Bauer, 17.
chemical, 16.
Villard's osmo-regulator, 17.
Rémy and Contremoulins process of localisation, 209.
Reports, medical, drawing up of, 939.
results of examination and preparation of, 1024.
Retinal sensitiveness, variations of, 33.
Richard and Colardeau stereoscope, 239.
Rifles, principal characteristics of, 130.
Ring pincers, 158.
Rinne's test for hearing, 959.
Robin, spring apparatus of, 735.
Rod for localisation of projectiles, 159.
"Rotary contacts," 12.
Rotary transformer, 68.
Rotation of artificial arm, prevention of, 469.
Roussel process of localisation, 203.
Roux, 647.
Rule, Mazérès, 192.

Sagnac, M., 42.
Saïssi compass, 170, 294.
Schwabach's test, for hearing, 959, 964.
Sclerosis, interlobar, oblique rays in diagnosis of, 59.
of muscle, in congenital torticollis, 713.
in ischæmic contracture, 714.
in war wounds, 712–717.
Screen, direct extraction, and its advantages, 322.
Screen, distance from anticathode, 186.
fluorescent, 29, 30, 82, 296.
and the fluoroscopic image, 29.
illumination of, 30.
operations in red light, 301, 302.
visibility of projectiles on, 105.
Screen examination, apparatus for, 82.
disfavor of, 103.
easily made mistakes in, 116.
errors of diagnosis, 121.
photographic imperfections in, 117.
Screen localisation methods, 174.
Screens, intensifying, 38, 40.
Searcher-localiser, 367.
Secondary radiation, 41.
"Sector-guide" of Grandgérard, 169.
Sédillot, 655–656, 659.
Senn, 667.
Sensitiveness, luminous and visual, 31.
Sequestra, formation of primary and secondary, 612–613.
removal of, importance of, 655.
treatment of, operative, 653.
Sequestrum formation following contusion, 606.
Serous membranes, movable projectiles, 272.
Shadowgraphs, Chinese, 29.
Shells, 137 *et seq.*
description of, 137, 139.
description of action of, 139.
Shields, opaque, 95.
"Short circuit," how caused, 19.
Shortening of fragments, 542.
in femur, 546.
of humerus, 548.
in lower limbs, 548.
Shoulder, attachment of artificial forearm to, 467.
projectiles in, 267.
Shoulder joint, disarticulation through, artificial limbs for, 523.
effects of mal-united fractures of humerus on movements of, 757.
Shrapnel shells, 139.
Simulation of deafness, 934.
course to be followed in, 937.
etiology of, 934.
symptoms and diagnosis of, partial deafness, 936.

Simulation of deafness, symptoms and diagnosis of total deafness, 935.
Sinus, lateral, injury of, due to auriculo-mastoid wounds, treatment of, 880.
Sinuses, of bone, duration of, 692.
reopening of, 705.
See Cavities and Tunnels in Bone.
chronic, of bone, association of dermatitis with, 635.
association of joint troubles with, 643–644.
the result of compound fractures, clinical study, 625–647.
pathology of, 611–618.
radiographic study, 619–624.
the result of wounds of bones, 608–611.
epiphyses and flat bones, 608–611.
femur, 606–607.
skull, 605.
tibia, 606.
leading to epiphyses in ankylosis of joints, operation for, 698.
resulting from wounds of bone, without complete fracture of cancellous bone, 608.
and compound fractures, 602.
in shaft of, 604.
Sinusoidal curve, 24.
Skiameter of Viallet and Dauvillier, 194.
Skin, effect on, of friction from artificial limb, 388.
Skull, localisation of projectiles, in, 251.
search for foreign bodies in, 123.
Spade holder, 507.
Spark measurer, 19.
Sparking device for X-ray tubes, 19.
Spectacles, X-ray, 84, 97.
Spina ventosa, in osteomyelitis, 589.
Spine, projectiles in, 348.
localisation of, 265.
Spintermeter, 19.
Splinters, bony, 355.
due to projectiles, 355.
Spontaneous issue of sequestra, 639–642, 652.
Stereometer, 241.
Stereometry, in determining position and depth of projectiles, 240.
Stereoradiographic scale, 242.
Stereoscopes, Hirtz, 237.
"Mexican," 238.
Pirie, 238.
Wheatstone, 237.
Stereoscopic radiography, 237. *See also* Radio-stereoscopy.
Stereoscopic radioscopy, 244.
Stereo-telescope, Mattey, 238.
Stereoscopy and localisation, 235.
Stereothesimeter, 242.
Stiffness of joints, tendency to, 720.
treatment of, curative, 726.
accessory, 737.
correction by a succession of plasters, 735.
forcible correction, 733.
preventive, 716.
Stop, for amputation below knee, 456.
to limit extension of knee, 418.
Strohl process of localisation, 204.
Stump, bearing points of, 387.
condition of, allowing end bearing, 387.
force transmitted to bucket by, 382.
length of, 383, 390.
for artificial forearm, 473.
Sub-scapular region, projectiles in, 350.
Suspension, of artificial arms, 465, 509.
to condyles of humerus, 465.
to shoulder, 467.
to worker's arm, 518.
Syme's amputation, 457.
Syphilis, viii.

Tattooing, for localisation of important points on skin, 89.
Tattooing needles, 89.
Tattooing pencil, for localising important points on skin, 89.
Tauleigne - Mazo's radiostereometer, 241.
Telephone probe, 166, 372.
Teleradiography, definition of, 47.
Teleradioscopy, definition of, 47.
Tendons, after-effects of wounds in, 707.

Tendons, of joints, lesions of, 711.
treatment of, 726.
Tetanus, viii.
Thigh, amputation of, circular method of, 389.
artificial limbs for amputations through, with bearing upon ischium, 412.
without bearing upon ischium, 440.
combined mechanism for knee and ankle joints, 435.
conversion of articulated peg leg into leg with free knee movement and *vice versa*. 438.
peg leg and similar appliances, 408.
shape of top of bucket, 393.
suspension of thigh piece, 401.
modes of, 412.
walking with free flexion of knee, 413.
leather and steel, 400.
projectiles in, 270, 351.
wooden, 397.
Thigh bucket, shape of, 393.
Thigh corset, 453.
Thigh piece, for artificial limb, suspension of, 401.
by means of braces, 404.
combined method of, 406.
by means of a waist belt, 402.
Thorax, projectiles in, 336, 351.
localisation of, 254.
search for foreign bodies in, 124.
Thumb, automatic, 478.
Beaufort, 479.
spring grip, 477.
Tibia, appliances with bearing upon tuberosities of, 447.
pseudarthrosis of, 574.
Tinnitus, due to labyrinthine concussion, 904.
Tissues, elasticity of, 290.
Torticollis, congenital, 713.
Tram driver's bell, 505.
Trachea, foreign bodies in, 258.
Tracing boards, Blondin's, 216,
Transparency of bodies, 27.
tables of equivalents, Benoist's, 108.
Trench engines, 139.
Triangulation, Andrault and Barret process of, 205.
geometrical, 142.
particular cases of, 202.
Pierre process of, 204.
Trocar, electric, 371.
Trouvé's electric explorer-extractor, 370.
Tube stands, 76.
Tubes, X-ray producing. *See* X-ray tubes.
Tungsten disc, 8.
Tuning fork, deep-toned, 954.
in examination for deafness, 954.
high-pitched, 956.
unisonant, of Escat, 990.
Tympanic membrane and cavity, wounds of, anatomical course of, 854.
aseptic, 854.
symptoms of, 856.
treatment of, 862.
contusion, 853.
deafness due to, 856.
diagnosis of, 862.
etiology of, 851.
examination, objective, 857.
examination of hearing, 857.
infected, 855.
other lesions due to, 856.
otorrhagia due to, 856.
pathogenesis of, 852.
pathological anatomy of, 853.
prognosis of, 861.
rupture of membrane, 853.
suppurative, symptoms of, 859.
treatment of, 865.
symptoms of, 856.
treatment of, 862.
immediate, 862.
later, 863.
Tympanic prothesis, 863.
Typhoid fever, vii.

Ulceration, in amputation stumps requiring further operation, 585.
Ulna, mal-united fractures of, resulting in limitation of range of supination, 759.

Valan, emulsion of, 674.
Valleé, 649.
Venesection, in chlorine gas poisoning, 775.

Vergely method of localisation of projectiles, 164.
Vertebral column, 265.
Vessels, projectiles in, 352.
Viallet and Dauvillier skiameter, 194.
Vibrating electro-magnets, 361.
Viewing box, 88.
Villard valve, 11.
Villard's osmo-regulator, 17.
Vine-dresser's hand, 493.
Visibility, 155.
of projectiles on the screen: its conditions, 105.
Vision, binocular, in radiology, 31.
Visual function in radiology, 31.
Voltage, high, for production of X-rays, 1, 8.
measuring of, 18.
product of, estimated by intensity of a current, 9.
in relation to amperage, in production of X-rays, 9, 10.
Voltmeters, use of, 18.

Waist belt for suspension of thigh piece, 402.
War, radioscopic process in, 102, 173, 207 *et seq.*
War deafness. *See* Deafness.
War radiography, vertical and recumbent examinations, 76.
War radiology, an important point in, 48.
Warluz and Jollant, method of localisation, 228.
Water-cooled tube, double anticathodal, 248.
Watt, definition of, 9.
Wave, definition of, 11.
Wave lengths, measuring of, 26.
in proportion to velocity of electrons producing, 26.
table of, 25.
Weber's test for hearing, 959, 966.
Wheatstone stereoscope, 237.
Worker's arm, 518.
Wounded, methods of disposal of, after cure, 787.
Wounds, after-effects of, burns, 777.
defects of bony union, 541.
gas infection and gas gangrene, 763.
in joints, muscles and tendons, 707.
osteomyelitis, chronic traumatic, 578.
Wounds, of bone, of shaft of, 604.
sinuses resulting from, 604.
of ear, in auricle, 847.
in auriculo-mastoid region, 867.
of external auditory meatus, 849.
of tympanic membrane and tympanic cavity, 851.
infection of, frequency of, in war, 598.
Wrist, projectiles in, 351.
Wullyamoz, 80, 83, 298.
fluoroscope of, 83.
Wullyamoz process, 297.

X-radiations, of equal wave length, identical in properties and effects, 25.
estimation of quality of, 26.
hard or penetrating, 23.
primary, 42.
secondary, 43.
deleterious effects of, 43.
impossibility of suppressing entirely, 44.
means for eliminating action of, 43.
soft, or of slight penetration, 23.
table of wave lengths including, 25.
wave lengths of, in proportion to velocity of electrons producing, 26.
wave series extending from centre of propagation of, 24.
X-ray accessory material, 88.
X-ray aluminum filter, use of, 96.
X-ray apparatus, accessory materials, tattooing needles, Dr. Henry Béclère's, 89.
for conducting the examination, 75.
X-ray appliances, 87.
X-ray dermatitis, occurrence of, 93.
X-ray diaphragm, importance of use of, 96.
X-ray examination, cases of undiscovered projectiles, 100.
and "explosive effects" of projectiles, 132.
of fractures, 64.
specimen report of, 126.

X-ray images, interpretation of, 62.
distinguishing differences in intensity of shadows, 66.
knowledge of normal X-ray anatomy of skeleton necessary to, 66.
on a single plane, 65.
taken in frontal and sagittal planes, 66.
in two planes at right angles, necessity of, 64.
in various planes, 65.
X-ray interpretation, importance of normal ray and properly centred tube in, 55.
primary ideas on, 46 *et seq.*
X-ray localisation of projectiles. *See* Projectiles, localisation of.
X-ray plates. *See* Plates.
X-ray projections, approximating region to be examined as near as possible to plane of, 49.
conical, 47.
distortion in, 48.
factors to be determined in, 48.
laws of, and laws of conical projections, 47.
maintaining same incidence in relation to plane of, 48.
and the normal ray, 46.
orthogonal, 61.
of radiological images, 47.
shadow produced by bullet 47.
X-ray report, 126.
X-ray shields, 74.
importance of use of, 95.
and tube-holders, 74.
X-ray skin pencil, 89, 157.
X-ray surgical table, 79.
X-ray table, 76, 78.
X-ray tube holders, 74.
X-ray tube stand, 76.
X-ray tubes, adjustment of, 12.
American manufacture of, 20.
anticathode serving also as anode in, 5, 6.
"break-downs" and other troubles with, methods of remedying, 16.
principal cause of, 16.
centring of, 49.
device for, 54.
effecting of, 52.
importance of, 51.
X-ray tubes, centring of, incorrect, and result of, 58.
instruments for, of French manufacture, 51.
Chabaud, 20.
with chemical regulator, 16.
Coolidge, 20.
Crookes', 3.
displacement of, 187.
by foot levers, 237.
radioscopic, 175.
radiographic processes, 207 *et seq.*
with double image, 187.
double anticathodal, 245.
water-cooled, which can be placed under radiological table, 248.
for localisation purposes, 226.
electrodes of, 1.
"equivalent spark gap," 19.
fluorescence produced in, 13.
French manufacture of, 20.
gases evolved in, 15.
German manufacture of, 20.
"interior atmosphere" of, 15.
Jackson's, 4.
production of current in, 1, 2.
production of electrons in, 2.
with punctiform focus, 7, 8.
regulation of working of, importance of, 15.
regulators for, 16 *et seq.*
air, or Bauer, 17.
chemical, 16.
Villard's osmo-regulator, 17.
resistance of, 19.
shield or protective box for, 49.
"short circuit" in, 19.
sparking device for, or spintermeter, 19.
starting the apparatus, 13.
suitable for army use, 73.
tendency to become hard, 15, 16.
"Villard" valve type, 11.
X-rays, action of, in proportion to distance from screen, 30.
biological effects and dangers of, 92.
dermatitis, 93.
precautions against, 95.
and their chief properties, 21.
as compared with luminous rays, 23.

X-rays, dangers of absorption of, 318.
dangers and injuries to tissues, 327.
discovery of, 153.
historical survey of, 153.
normal ray, definition of, 48.
oblique, use of, 59.
permeability of bodies to, 21.
aluminum, 26.
aluminum in relation to silver, 27.
in relation to atomic weight, 22.
in relation to state of tube, 23.
X-rays, permeability of bodies to silver, 27.
unequality of, 21.
production of, 1–3, 23.
amperage and voltage in, 9, 10.
high voltage source of electric energy for, 8.
utilisation of electric energy in, 9, 10.
property of, in rendering bodies fluorescent, 29.
punctiform source of, 7.

Zimmern's anatomical sections, 250.